IDENTIFICATION OF THE SPAWNING, REARING, AND MIGRATORY REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

Annual Report 1991

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IDENTIFICATION OF THE SPAWNING, REARING, AND MIGRATORY

REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

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1991 Annual Progress Report

August 1991 - July 1992

To

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EXECUTIVE SUMMARY

        This document is the 1991 annual progress report for
selected studies of fall chinook salmon Oncorhynchus tshawytscha
conducted by the U.S. Fish and Wildlife Service (USFWS).
Activities were funded by the Lower Snake River Compensation Plan
of the USFWS and the Bonneville Power Administration (BPA)
through funding of Project No. 91-029.

        The decline in abundance of fall chinook salmon in the Snake
River basin has become a growing concern. In April 1992, Snake
River fall chinook salmon were listed as "threatened" under the
Endangered Species Act. Effective recovery efforts for fall
chinook salmon can not be developed until we increase our
knowledge of the factors that are limiting the various life
history stages. This study attempts to identify those physical
and biological factors which influence spawning of fall chinook
salmon in the free-flowing Snake River and their rearing and
seaward migration through Columbia River basin reservoirs.

        Fall chinook salmon spawning information was collected in
the Hells Canyon Reach of the Snake River. During the 1991
spawning period, flows in Hells Canyon were lower and water
temperature warmer than the historical records we examined.
About 98% of the varibility in water temperatures at sites we
studied during the spawning period was explained by the
temperature of water released at Hells Canyon Dam and the air
temperature 30 d prior to release. Redds were counted from the
air by helicopter with subsequent ground truthing and SCUBA
surveys. Some redds were found by SCUBA in water too deep for
detection by helicopter. Despite increased counting effort by
helicopter, the 1991 index redd count of 32 was down from the
recent high of 66 redds in 1987. Most spawning occurred in
November with redds being unevenly distributed longitudinally
within the river. Fourteen of 32 redds (i.e. 44%) counted during
the index flights, were located at Snake River kilometer (RK)
261. Depths measured within the bounds of the spawning area at
RK 261 ranged from about 0.5 to 1.5 m, and water velocities
ranged from just under 0.5 to 1 m/s.

        Migratory behavior of subyearling fall chinook salmon was
examined in laboratory swimming performance tests. Hatchery and
migrating juveniles displayed their greatest inclination to
migrate during June and July when they were 7 to 10 cm in length.
Fish swam upstream in a swim flume at velocities less than 2.5
body lengths per second, and passive drift was rarely observed.
Migrating fish tended to be displaced at greater rates during the
night than during the day except in June when they actively swam
downstream when water velocities exceeded 30 cm/s. There was no
correlation with maximum swimming velocity and gill Na+K*-ATPase
activity.

Subyearling fall chinook salmon were marked at McNary Dam to relate river flow and migration patterns of juvenile salmon to adult returns. A total of 108,000 fish emigrating during the early, middle, and late segments of the migration were successfully coded wire tagged and released at McNary Dam. Delayed mortality and tag loss of 1.0% was acceptable. Adequate numbers of branded fish were recaptured at John Day and Bonneville dams to determine that the three groups of fish maintained their integrity and emigrated separately in relation to when they were released. Travel time of subyearling chinook salmon through John Day Reservoir was significantly correlated with river flow and gill ATPase activity but not with date of release, temperature, or fish size.

The use of PIT tags in subyearling fall chinook salmon was evaluated in laboratory tests. A comparison of U-critical swimming speed of PIT-tagged and control fish indicated that any effects from tagging on swimming performance are relatively short term, probably 4 h or less. PIT-tagged fish exposed to smallmouth bass *Micropterus dolomieui* predation were preyed upon at a higher rate than control fish when allowed a 0.5 h recovery time, but the numbers of tagged and control fish consumed were similar when allowed a 96 h recovery period prior to predation risk. Sham-tagged and control fish were not differentially preyed upon suggesting the presence of the PIT tag contributes to higher predation rates on tagged fish. Predation of PIT-tagged fish was not size selective. Maximum delayed mortality of PIT-tagged fish ranged up to 27% in some of the first trials conducted and occurred primarily within 24 h of tagging. Rearing tagged fish for 90 d indicated only a 1% total mortality rate was attributable to PIT-tagging.

PIT-tagging juvenile fall chinook salmon in the Hells Canyon Reach and subsequent detection at Lower Granite Dam was used to study emigration patterns in the Snake River. Beach seines were used to sample naturally produced juvenile fall chinook salmon from the Snake River between RK 211 and 250. We PIT tagged salmon $\geq$ 55 mm using size criteria to judge race. A genetic analysis of PIT-tagged chinook salmon recaptured at Lower Granite Dam indicated 94% of the fish originally tagged were fall chinook salmon. Juvenile fall chinook salmon showed relatively high fidelity to near-shore areas. Most chinook salmon began leaving near-shore areas in late June at about 85 mm fork length with a peak arrival at Lower Granite Dam occurring in late July at a mean length of 127 mm. Mean migration rate to Lower Granite Dam was 2.3 km/d and was significantly influenced by salmon size, flow, and water temperature at release.

ACKNOWLEDGEMENTS

CHAPTER ONE

Fall Chinook Salmon Spawning
in Free-Flowing Reaches of the Snake River

by

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Introduction

Knowledge of fall chinook salmon *Oncorhynchus tshawytscha* spawning and habitat characteristics in the free-flowing Snake River is urgently needed. When the National Marine Fisheries Service was petitioned to list Snake River fall chinook salmon under the Endangered Species Act (ESA; United States Fish and Wildlife Service 1988), the spawning data base consisted of unauthenticated redd counts by air (Irving and Bjornn 1981a; Seidel et al. 1988, Buggert et al. 1989-1990) and an 18 year-old flow versus habitat study (Bayha 1974). With the ESA petition came renewed interest in obtaining information on Snake River fall chinook salmon spawning since our present understanding was not sufficient for recovery planning.

Our 1991 work was a pilot study to establish field techniques and guidance for the remainder of the project. study objectives were: (1) describe the distribution of fall chinook salmon redds in the Snake River; (2) describe the refinements being made in fall chinook salmon redd counting procedures; (3) characterize the physical features of fall chinook salmon spawning sites and present a preliminary estimate of seeding level; and (4) describe Snake River discharge and water temperatures during the fall chinook salmon immigration, spawning, and egg incubation periods of the 1991 brood year.

Study Area

The study area included the Snake River from Hells Canyon Dam to its mouth (Figure 1). We describe specific locations within the area in terms of river kilometers (RK) based on the navigation charts of the Snake River produced by the United States Army Corps of Engineers (COE). Our main focus in 1991 was on the free-flowing reach of the Snake River between Hells Canyon Dam (RK 398) and the head of Lower Granite Reservoir near Asotin, Washington (RK 235).

WASHINGTON

Lower Granite Dam

Little Goose Dam

Lower Monumental Dam

Columbia River

Cearwater River

Dworshak Dam

Ice Harbor Dam

McNary Dam

Grande Ronde River

Imnaha River

Salmon River

OREGON

Hells Canyon Dam

Oxbow Dam

Brownlee Dam

Snake River

IDAHO

Lower Granite Dam (RK 173)

Lower CGranite Reservoir

Lewiston

Asotin (RK 235)

RK 245

RK 261

RK 265

Anatone (RK 270)

RK 287

RK 303

RK 308

RK 312

RK 347

Swan Falls Dam

C.J. Strike Dam

Bliss Dam

Lower Salmon Falls Dam
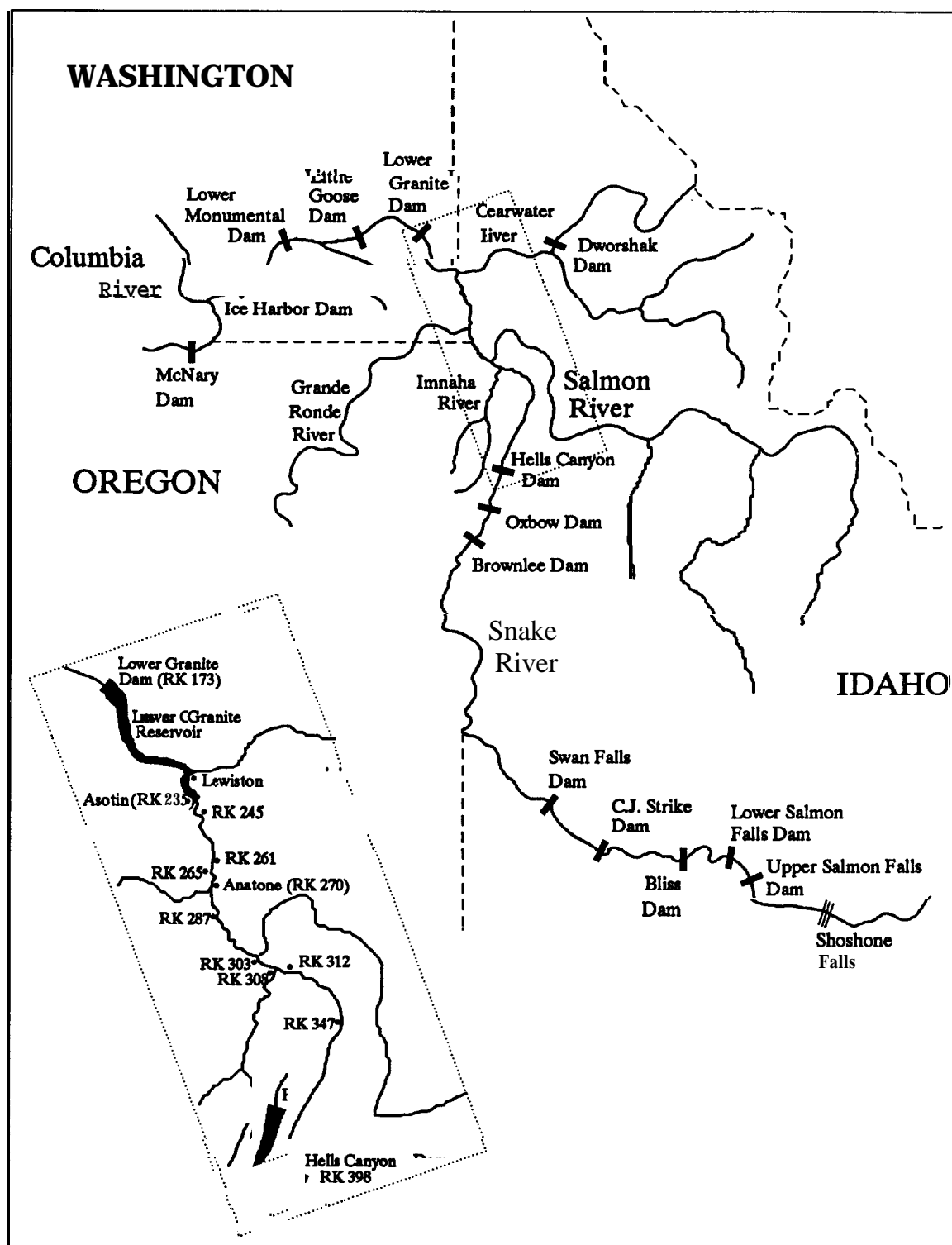
Upper Salmon Falls Dam

Shoshone Falls

Hells Canyon RK 398

Figure 1. Map of the Snake River draimag with inset showing the 1991 fall chinook salmon spawning study site at RK 261, Anatone Gage at RK 270, Hells Canyon Dam at RK 398, and thermograph locations (refer to Table 1 for river kilometers).

Methods

Data Collection

Redd counts.- Fall chinook salmon redd count data were collected by helicopter using an interagency team from 1987-1991. These data were originally published by the Washington Department of Fisheries (Seidel et al 1988, Bugert et al. 1989-1991, Bugert 1991, and Mendel et al. 1992). From 1987-1989, aerial counts of fall chinook salmon redds were made about the second and fourth weeks of November. These aerial counts are referred to hereafter as "index counts." Each index count covered the river from Asotin, Washington (RK 235) to Hells Canyon Dam (RK 398), unless the weather became inclement. The river was scanned for fall chinook salmon redds by observers while the helicopter flew up and downriver at an altitude of 100 to 200 m. When a potential redd was located, the pilot positioned the helicopter for optimal viewing and an observer noted the location of the potential redd on COE navigation charts. In 1990, based on interagency consensus, we added a third index count in early December to check for late fall chinook salmon spawning activity.

Refinements in redd counts.- Starting in 1991, we increased the counts from 3 to 9 to better define the timing of fall chinook salmon redd construction. The 9 counts were made weekly from 14 October to 9 December. Notably, the weekly counts included index counts on 11 November, 26 November, and 9 December.

We did not authenticate fall chinook salmon redds counted from the helicopter from 1987-1990. Starting in 1991, all potential fall chinook salmon redds observed from the air were authenticated by ground truthing. Ground truthing involved wading a safe distance upriver and to the side of each redd's tail spill. Redd authenticity was based on pit and tailspill size, substrate composition, water velocity, and the presence of adult fall chinook salmon. Locations of confirmed fall chinook salmon redds were mapped by a licensed surveyor. The locations of shallow-water redds were recorded by sighting a prism on a pontoon positioned over the redds by rope.

We used SCUBA to count fall chinook salmon redds at RK 261 in water too deep to allow detection from the air or by wading. Two SCUBA divers holding planing boards were towed 38 m behind a boat along five adjacent transects. The first transect began on the deep-water edge of redds initially located by air and which were then mapped by the surveyor using the shallow-water method described previously. Subsequent passes were initiated progressively toward the opposite shore. Divers communicated with the boat pilot using voice activated radios to relay observations of redds or changes in the substrate of the river bottom. The diameter of the dominant and subdominant substrate

was visually estimated as was the percent fines between them. These data were coded using the Brusven index (Brusven 1977) which is composed of a number for each of the above three substrate types. Once data were announced to the boat pilot and recorded, they were relayed by radio to the surveyor on shore. The surveyor recorded the position of the redds or substrate codes by sighting the position of a pontoon equipped with a prism array towed directly above the divers.

*Physical features of spawning sites.-*We used the Instream Flow Incremental Methodology (IFIM; Bovee 1982) to collect habitat data at fall chinook salmon spawning sites. We collected channel elevations, water surface elevations, water velocities, and substrate codes at cross sections placed in key locations at each spawning site. Some cross sections were also placed through the middle of homogeneous channel reaches surrounding the spawning areas. The downstream cross section at each site was always placed at a point of hydraulic control. Because of frequent boat traffic we did not stretch a cable across the channel for positioning our gaging boat. Instead we fixed a prism to the bow of our gaging boat and surveyed the location of each flow measurement as we progressed across the channel. We also collected channel elevations and substrate codes between the IFIM cross sections to allow detailed site mapping. Onshore and shallow-water channel elevations and substrate codes were measured by sighting a prism on a rod at the point of data collection. Offshore channel elevations were collected using a boat equipped with sounding gear and a prism for surveying measurement locations. Offshore substrate data were provided by the SCUBA divers while counting fall chinook redds.

Discharge and water temperature.- Snake River discharge data for the Anatone Gage, Washington (RX 270) were furnished by the United States Geological Survey (USGS) for the 1967-1992 time period (Appendix 1). The USGS also provided Snake River discharge data for the Brownlee, Oxbow, and Hells Canyon Dam Complex (Hells Canyon Dam Complex), and the Imnaha, Salmon, and Grande Ronde rivers for the 1991-1992 time period (Appendix 2). Water discharge data are reported in this chapter in thousands of cubic feet per second (KCFS) based on USGS standards.

Snake River water temperature data were collected at the Anatone Gage from 1975-1982 by the USGS (Appendix 3). Water temperature data were also collected at 10 locations (Table 1; Figure 1) by the United States Fish and Wildlife Service using thermographs (Appendix 4).

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Table 1. Snake River drainage thermograph locations by river kilometer and landmark, 1991.

River km	Landmark
398	Hells Canyon Dam outflow
398	Hells Canyon air temperature
347	Pittsburg Landing
312	Zig Zag Creek
308	In the Imnaha River
303	Chalk Creek
302	In the Salmon River
287	Cochran Islands
271	In the Grande Ronde River
265	Billy Creek

Data Analysis

Redd counts.-Data from the index counts are summed over time to show total fall chinook salmon redd counts by year, day, and river kilometer from 1987-1991.

Refinements in redd counts.- Redd construction timing was analyzed from weekly fall chinook salmon redd counts from 1991. Additionally, we used data collected on 26 November by index count, ground truthing, and deep-water counts of fall chinook salmon redds to compare the results of each technique at RK 261 under the 1991 water conditions.

Physical features of *spawning habitat.-* Substrate data analysis is limited to a map of the graveled area at RK 261 used by spawning fall chinook salmon in 1991. We also present velocity distributions collected at RK 261 on 12 November of 1991 to characterize the velocity ranges utilized by spawning fall chinook salmon. A preliminary estimate of seeding level at RK 261 was made by multiplying the number of redds at the site by 17 m^2 (the area of Columbia River fall chinook redds; Chapman et al. 1986) and dividing this number by the total area of wetted gravel.

Snake River discharge and water temperatures.- We used our 1992 unpublished data to define the timing of each fall chinook salmon life stage in the 1991 brood year (25 August, 1991-12 May 1992) for relation to discharge and temperature. A historical perspective of Snake River discharge at Anatone Gage is given by comparing 1991 brood year discharge data to discharge data collected the first 20 years after the completion of Hells Canyon Dam Complex in 1967.

We analyzed Hells Canyon Dam Complex, Imnaha, Salmon, and Grande Ronde River discharge data from the 1991 fall chinook salmon brood year to demonstrate the potential effect each water source had on main stem Snake River flow at Anatone Gage. Part of this analysis was based on the percentage of discharge contributed by each of the above water sources. we also examined daily changes in the discharge at the Anatone Gage relative to changes in discharge of each of the above water sources.

As in our discharge analysis, we also used the life stage timing of the 1991 fall chinook salmon brood year as part of the water temperature analysis. Historical water temperature data from 1978-1982 at Anatone Gage were compared to thermograph data collected at RK 265 in 1991 during each fall chinook salmon life stage. In addition, we analyzed 1991 brood year water temperature data from our thermographs by river kilometer to test for differences between up and downriver temperatures.

A two-step regression analysis was applied to Hells Canyon air temperature (RK 398) and Hells Canyon Dam Complex outflow temperature (RK 398) data to describe the relation between these two variables. The air temperature data were analyzed in intervals (number of days air was measured before outflow) of 1, 7, 14, 21, and 30 d to account for reservoir turn over time. First, the appropriate air temperature data for a final regression model was selected. This selection was based on standardized coefficients calculated for each air temperature interval using Multivariate General Linear Hypothesis testing (MGLH; SYSTAT 1990). The MGLH model was initiated with data from two air temperature measurement intervals (i.e. 1 and 14 d) and consecutive runs were made by adding new interval data and removing data with low standardized coefficients and insignificant t-values. The air temperature measurement interval with the highest standardized coefficient was selected for the final simple linear regression on Hells Canyon Dam outflow temperature on air temperature to produce a regression coefficient (r^2).

We also used MGLH to analyze the relation between main stem Snake River water temperatures, Hells Canyon Dam Complex outflow temperature, Imnaha River water temperature, Salmon River water temperature, and Grande Ronde River water temperature. Data from RK 312 and RK 265 were used to represent Snake River temperatures above and below the Imnaha and Grande Ronde Rivers, respectively. We used the standardized coefficients produced by MGLH to analyze the effect of each independent variable on water temperature at RK 312 and RK 265. The significance of the model was based on the p-value and regression coefficient (R^2).

Results

Redd Counts (1987 to 1991)

During the "two-index-count" years of 1987, 1988 and 1989, the total number of fall chinook salmon redds counted were 66, 57, and 58, respectively (Table 2). The total redd count for the first two index counts in 1990 was 32 and we counted 5 additional redds (13.5% of the total index count) during the third index count for a total of 37. The total redd count for the first two index counts in 1991 was 31 and we counted 1 additional redd (3.1% of the total index count) during the third index count for a total of 32.

Fall chinook salmon redds counted during the 1987-1991 aerial index counts were distributed between RK 239 and RK 398 (Table 2; Figure 2). Fourteen of the redds (44% of total index count) were at RK 261 near Captain Johns Creek in 1991. All 14 of the redds at RK 261 were counted during the 11 and 26 November index counts. Concentrated spawning occurred downstream at RK 245 near Big Bench Point from 1987 to 1990; no redds were observed at this site in 1991.

Refinements in Redd Counts

A total of 41 fall chinook salmon redds were counted during the nine weekly counts in 1991 (Table 3; Figure 3). No redds were observed on 14 or 21 October. The first fall chinook salmon redd was seen on 28 October. Redd counts peaked on 18 November and the last new redd was counted on 9 December.

The total weekly count of fall chinook salmon redds at RK 261 was 15 by 26 November. On 26 November at RK 261, we ground truthed 11 redds by wading and 9 redds by SCUBA for a minimum count of 20 redds (Figure 4). Therefore, at least five redds (25% of minimum redd count) at RK 261 were in water too deep for detection by air on 26 November.

Physical Features of Spawning Habitat at RK 261

Dominant spawning gravel around fall chinook salmon redds at RK 261 was 2.5 to 15.0 cm in diameter (Figure 5). Depths measured at the cross section in Figure 5 ranged from 0.7 to 2.0 m, while velocities ranged from 0.55 to 1.22 m/s (Figure 6). Spawning gravel area at RK 261 exceeded 9,300 m^2; 76% of which was under flowing water at the time data were collected (Figure 5). Since the minimum redd count was 20 and each redd occupied a surface area of approximately 17 m^2, roughly 5% of the wetted spawning gravel at RK 261 was utilized by spawning fall chinook salmon in 1991.

Table 2. Summary of index counts of fall chinook salmon redds on the Snake River, 1987-1991 (from Seidel et al. 1988, Bugert et al. 1989-1991, Bugert 1991, and Mendel et al. 1992).

River km	Landmark	1987		1988		1989		1990			1991		
		9-NOV	23-NOV	14-NOV	I-DEC	13-NOV	27-NOV	12-NOV	26-NOV	11-DEC	11-NOV	26-NOV	9-DEC
240.5	Ten Mile Rapids	-	-		•	-	1	1	•	-	1	-	
244.4	Ten Mile Canyon	-		•	1	-	1	-	•	-	-	-	
245.2	Big Bench Point	-	13	4	4	20	3	8	4	4	-	-	
252.6	Warehouse at Couse Creek	-	•	•	-	-	1	-	1	-	•	-	-
261.3	Captain Johns Creek	-		•		1	-	-	2		-	11	3
262.6	Captain John Rapids	-	3		2	-	-	2		-	•	-	-
265.0	Billy Creek Rapids	2		5		1	1			1	-	-	-
266.0	Fisher Gulch	-	4	•		-	-			-	-	-	
266.6	Upper Billy Creek Rapids	-	2	10	4	-	-			-	-	-	
268.1	Lower Lewis Rapids	-			•	-	-			-	-	3	
272.7	Near Lewis Point	-		•		1	-			-	-	-	
277.6	Deer Head Rapids		1		•	-	-			-	-	-	
279.8	Below Shovel Creek	-	1	•	•	-	-	•		-	-	-	
287.9	Cochran Island Read	-				1	-	•		-	-	-	
307.3	Eureka Bar	-	1	1	4	-	-	2	•	-	1	2	
308.4	Near Imnaha River	-	2		4	-	-			-	-	-	
311.0	Above Divide Creek	4	•	•	•	5	-		2	-	-	-	
311.7	Divide to Zig Zag				•	-	-	•	3	-	-	-	
312.3	Above Zig Zag Creek	-	2		2	-	-		2	-	-	-	
315.7	Below Dug Bar, OR	1			3	-	-			-	-	-	
319.9	Above Robinson Gulch	-	1			-	-	2		-	-	4	
320.0	Below Deep Creek	4		•		3	-	•		-	-	-	
328.4	Near Blankenship Ranch	-	1			-	-	•		-	-	-	
330.2	Above Copper Creek	-				-	-	•		-	-	2	
330.8	Below Getta Creek		1			-	-			-	-	-	
332.1	Below High Range No.1	1		3	1	-	-			-	1	-	
334.4	Near Lookout Creek Range				1	-	-	•		-	•	-	
334.5	Below Lookout Creek			2		1	-	•		-	-	-	
337.4	Below Camp Creek		1			-	-	•		-	-	-	
343.7	Pleasant Valley Creek	-	-	•		-	2	-	1	-	-	-	
345.5	Near Pittsburg Range	2		•		-	-			-	-	-	
350.4	Durham Rapids		•	•	-	1	-			-	-	-	
351.1	Below Cat Gulch	1		•		-	-			-	-	-	
352.9	Kirby Range	-		2		-	-	•		-	-	-	
358.5	Near Suicide Rock	3		•		4	-			-	-	-	
359.9	Below Temperance Creek	-	•		1	-	-			-	-	-	
379.6	Near Hat Creek Mouth	4			2	3	-	-	•	-	-	-	
379.9	Below Saddle Creek		1			1	-			-	-	-	
380.9	Below Dry Gulch	1				-	-			-	-	-	
383.6	Above Three Creek Rapids	2				2	-	•	•	-	-	-	
387.1	Near Rocky Bar Camp	6				3	-	-	-	-	-	3	
391.5	Above Warm Springs Camp	-	1			1	-	-	-	-	-	-	
393.6	Below Brush Creek		-			1	-		2	-	-	-	
396.6	Near Rocky Point				1	-	-	•	•	-	-	-	
	Yearly Totals	66		57		58		37			32[a]		

[a] In 1991, 9 redds were observed during weekly counts that were not included in index counts (refer to Table 3), and at least 5 redds were observed by SCUBA divers at RK 261 that were not observed by air.

9

NUMBER

N = 250

Head of Lower Granite Reservoir — Big Bench Point — Cap tain hns Crk (RK 261) — Salm on Ri ver — Inaha River — Pittsburg Landing — Hells Canyon Dam
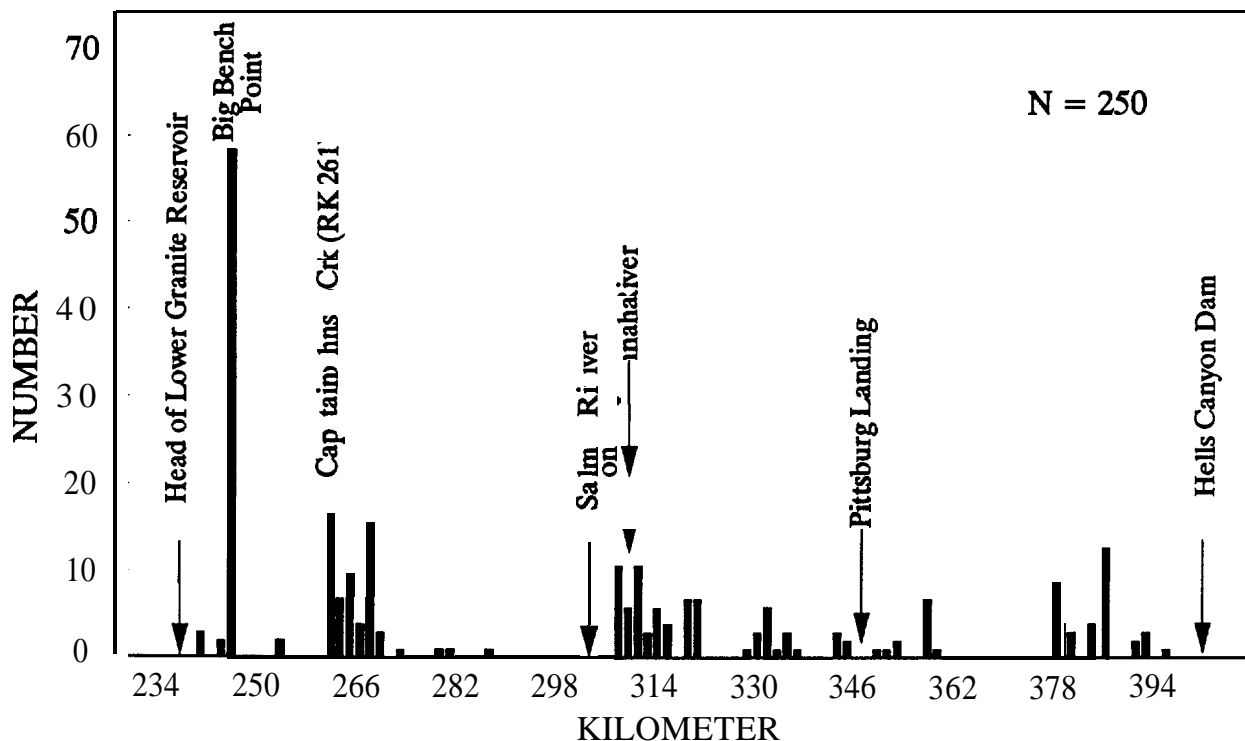
KILOMETER

Figure 2. Snake River fall chinook salmon redd number by river kilometer. Data were collected during index counts on the Snake River from 1987-1991 (Seidel et 1987, Bugert et al. 1989-1991, Bugert 1991, and Mendel et al. 1992).

Table 3. River kilometer (RK), landmark, and new fall chinook salmon redds counted by date during aerial surveys of the Snake River in 1991. No redds were observed during flights made on 14 and 21 October.

		New redds counted by flight date[a]							
RK	Landmark	28-Oct	04-Nov	11-Nov	18-Nov	26-Nov	02-Dec	09-Dec	Total
240.5	Ten Mile Rapids		1	1	-				2
261.3	Captain Johns Creek	1	7	3	4		-		15
265.0	Billy Creek Rapids	-	1	-	-				1
268.1	Lower Lewis Rapids	-				3	3	-	6
307.3	Eureka Bar			1	3				4
319.9	Above Robinson Gulch	-				4	1	-	5
330.2	Above Copper Creek	-			2	-		1	3
332.1	Below High Range No.1	-		1	-				1
387.1	Near Rocky Bar Camp	-		-	2	1	1	-	4
	Totals	1	9	6	11	8	5	1	41

[a] The 21 October flight covered the Snake River from Asotin, Washington (RK 235) to the mouth of the Grande Ronde River (RK 271).

10
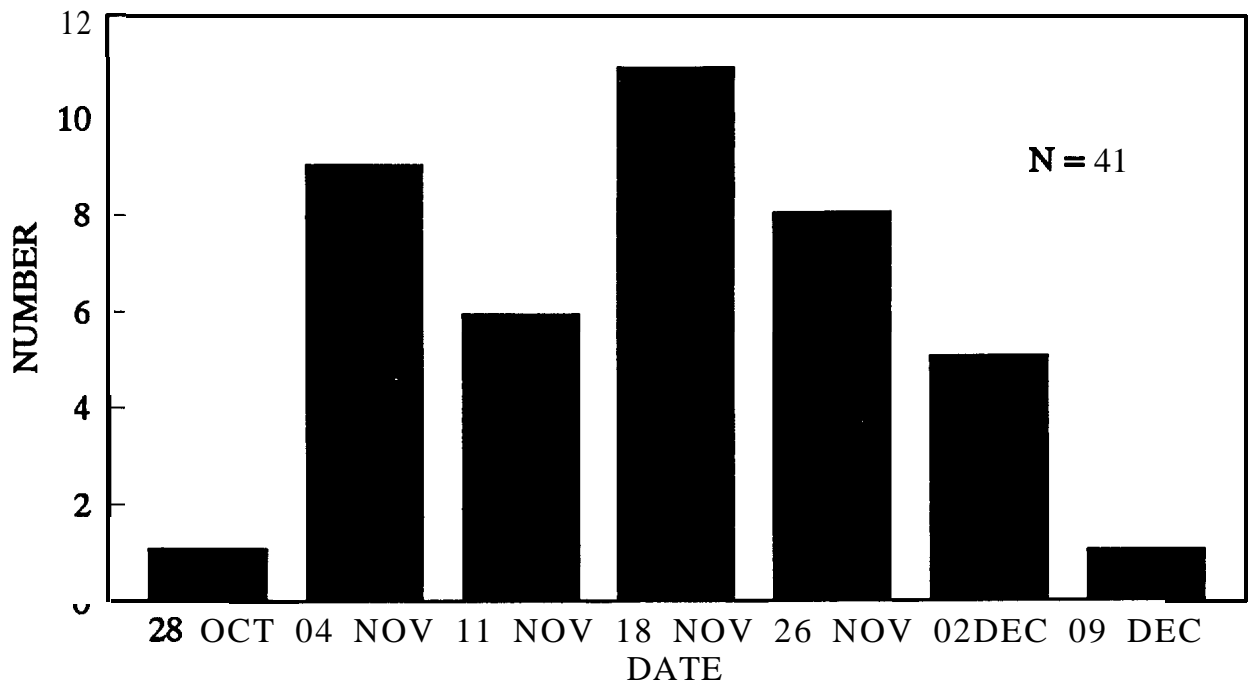
Figure 3. Number of new fall chinook salmon redds counted during each weekly
weekly counts on the Snake River. 14 October - 9 December, 1991. No redds were
observed on 14 or 21 October (Data from Mendel et al. 1992).
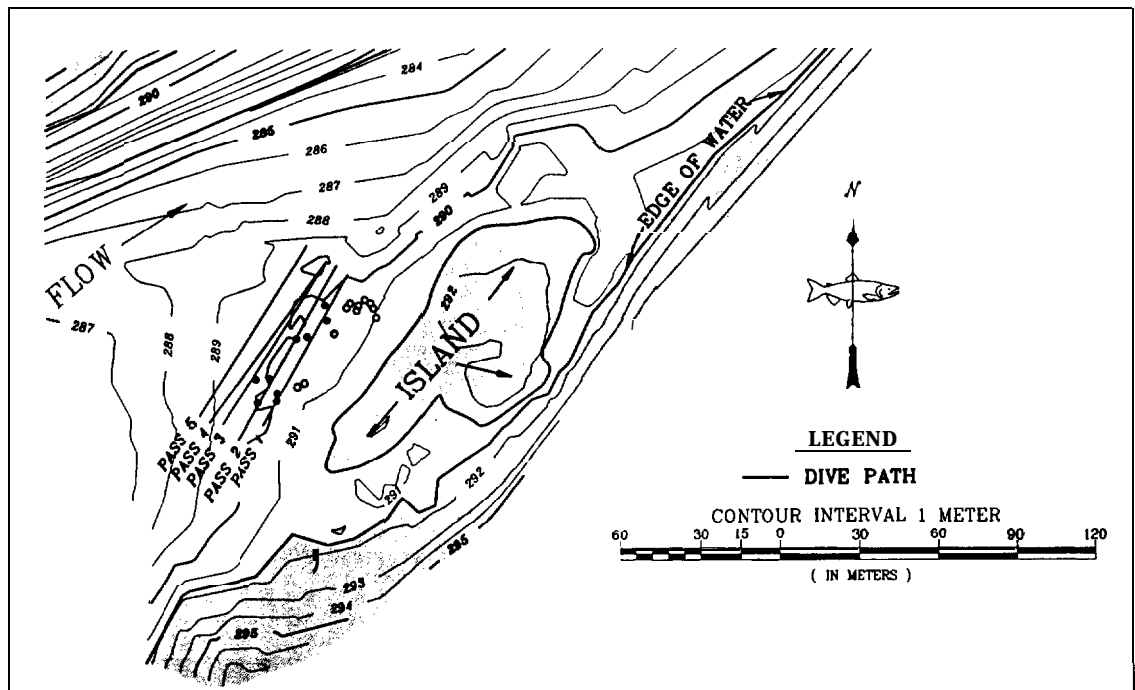
Figure 4. Snake River fall chinook salmon redd distribution at
RK 261 determined by wading (open circles) and by SCUBA (solid
circles), 26 November, 1991.
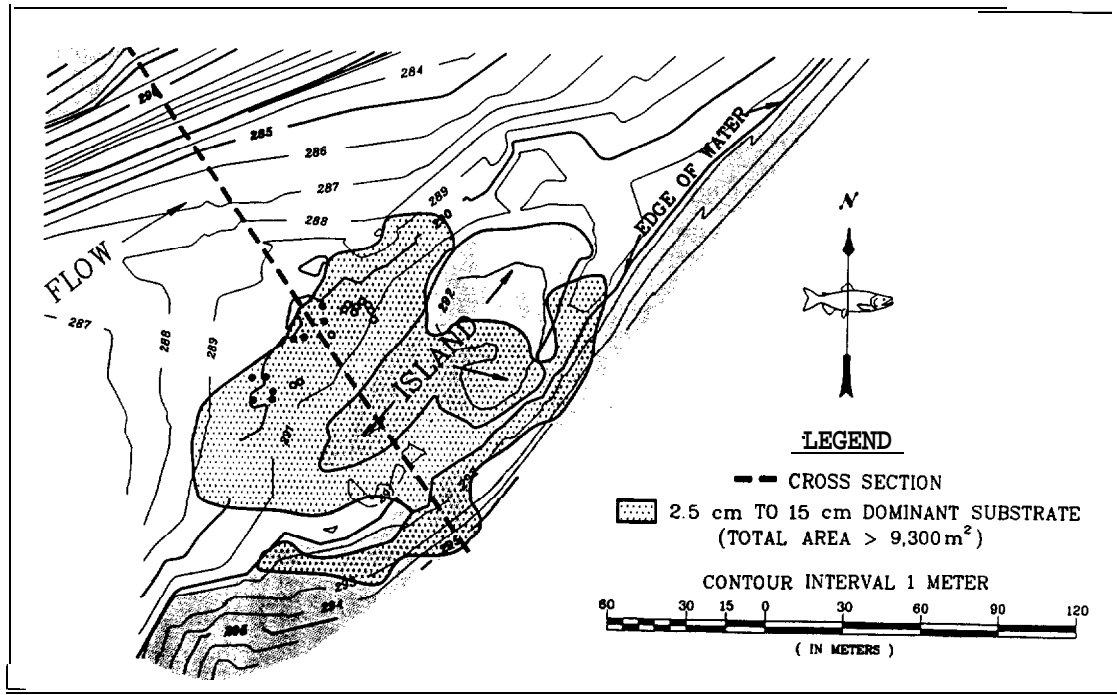
Figure 5. Spawning substrate distribution and area at RK 261.
Snake River fall chinook salmon redds located by wading (open
circles) and SCUBA (closed circles) are also shown, 26 November,
1991.
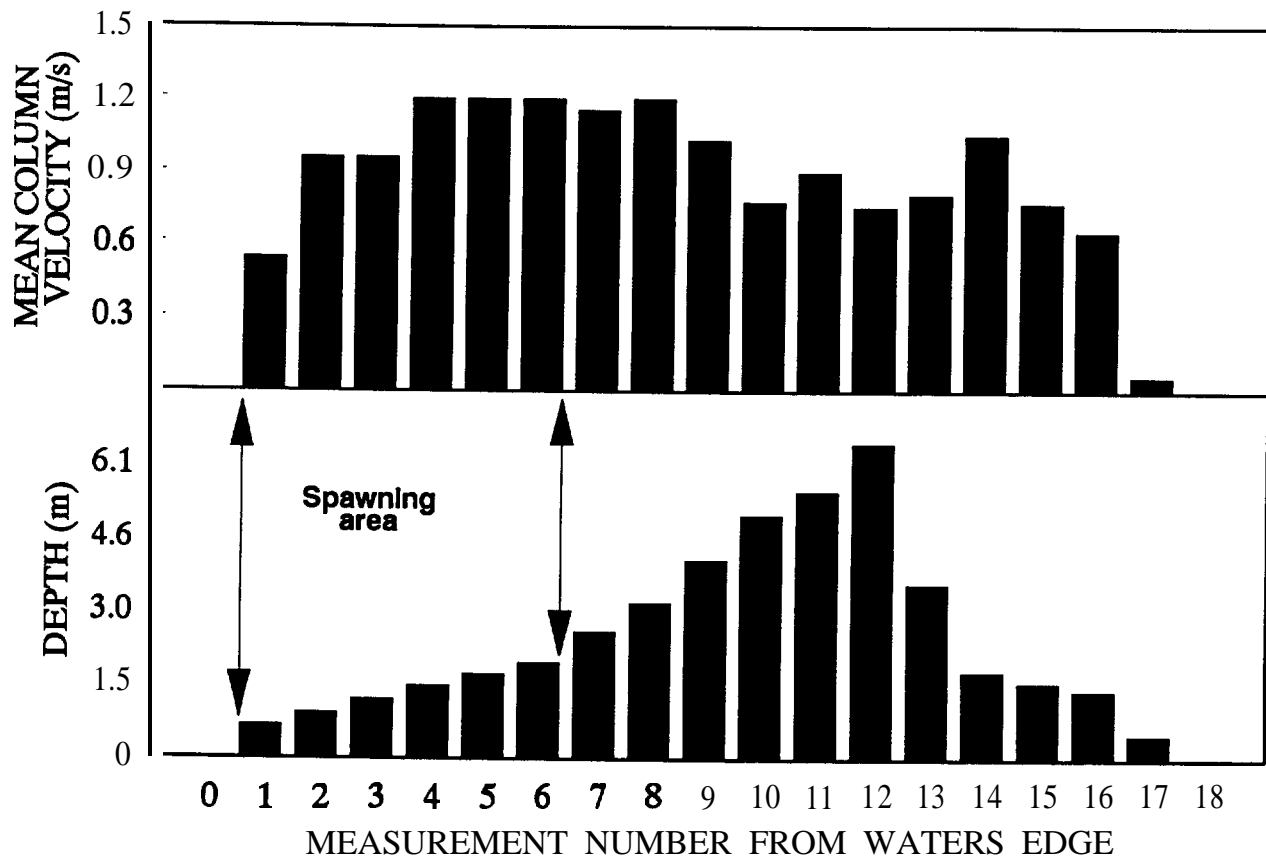
Figure 6. Water depths and velocities collected across the Snake River fall
chinook salmon spawning site at RK 261, 12 November of 1991. Refer to Figure
5 for cross-section location.

Snake River Discharge

　　　　Snake River average daily discharge for the 20 years after the completion of the Hells Canyon Dam Complex (in 1967) was higher than the average discharge over the 1991 fall chinook salmon brood year (Figure 7). The only time 1991 brood year discharge was higher than the 20 year average was 9 to 19 September, 1991 when flows averaged 22.6 KCFS. During the remaining 75 d of immigration fall chinook salmon faced discharges (average 14.9 KCFS; range 11.9-18.3 KCFS) that were 44% of the Hells Canyon Dam Complex 20 year average (33.7 KCFS; range 33.5-33.8 KCFS). During fall chinook salmon spawning, discharge (average 15.7 KCFS; range 13.9-19.5 KCFS) was about 60% of the Hells Canyon Dam Complex 20 year average (26.1 KCFS; range 23.2-28.8 KCFS). During fall chinook salmon egg incubation, discharge (average 20.7 KCFS; range 13.9-47.2 KCFS) was about 54% of the Hells Canyon Dam Complex 20 year average (38.5 KCFS; range 23.2-70.0 KCFS). During fall chinook salmon fry emergence, discharge (average 27.0 KCFS; range 18.4-47.2 KCFS) was about 49% of the Hells Canyon Dam Complex 20 year average (55.0 KCFS; range 44.9-70.0 KCFS).
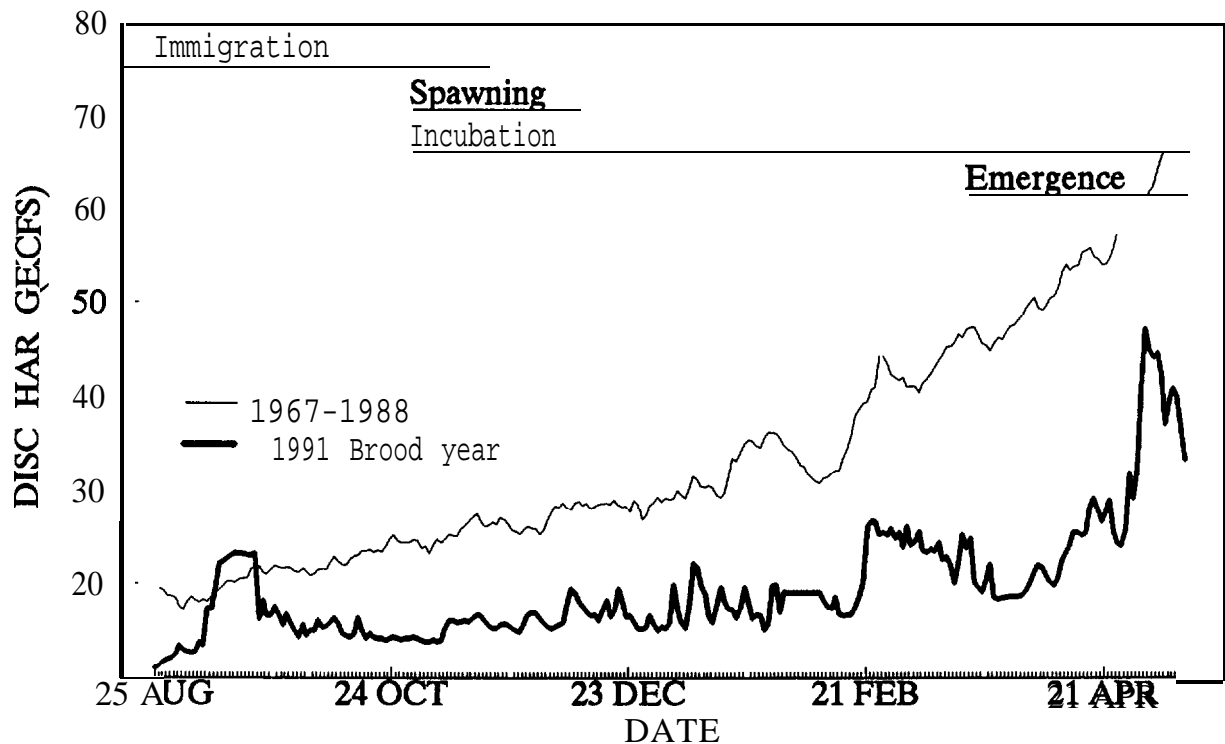
Figure 7. Snake River average daily discharge for 1967-1988 and the 1991 fall chinook salmon brood year. Discharge data were provided by the United States Geological Survey for Anatone Gage, Washington.

Hells Canyon Dam Complex contributed the majority of discharge to the Snake River at Anatone Gage during fall chinook salmon immigration (73%), spawning (61%), and early egg incubation (67%) for the 1991 brood year (Table 4). It was not until late in the fall chinook salmon egg incubation period that natural runoff from the Salmon River (36%) and Grande Ronde River (17%) contributed more flow (53%) than Hells Canyon Dam Complex (46%). Imnaha River contributed comparatively little discharge to main stem Snake River at the Anatone Gage (range 1-2%)

Table 4. Discharge contribution by Hells Canyon Dam, Imnaha River, Salmon River, and the Grande Ronde River to the main stem Snake River at the Anatone Gage of Washington during the 1991 fall chinook salmon brood year. Total flow does not always sum to 100 percent because the gage stations are not synchronized.

Life stage	Date	Percent of Snake River discharge contributed by source			
		Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River
Immigration	25 Aug - 18 Nov-91	73	1	24	4
Spawning	28 Oct - 9 Dec-91	61	1	28	9
Early incubation	28 Oct-91 - 5 Feb-92	67	1	23	9
Late incubation	5 Feb - 12 Way-92	46	2	36	17

Hells Canyon Dam Complex affected discharge stability at Anatone Gage through the 1991 fall chinook salmon brood year (Figure 8). The 11-d discharge spike from 9 to 19 September during fall chinook salmon immigration was the result of dam operation. Stable discharge (average 9.6 KCFS; range 9.4-9.8 KCFS) from the Hells Canyon Dam Complex from 28 October to 9 December during fall chinook salmon spawning had some stabilizing effect on fluctuation at the Anatone Gage (average 15.7 KCFS; range 13.9-19.5 KCFS). Most of the discharge fluctuation at the Anatone Gage during fall chinook salmon spawning was the result of Salmon River discharge (average 4.4 KCFS; range 3.6-5.6 KCFS) and Grande Ronde River discharge (average 1.4 KCFS; range 0.6-3.9 KCFS).

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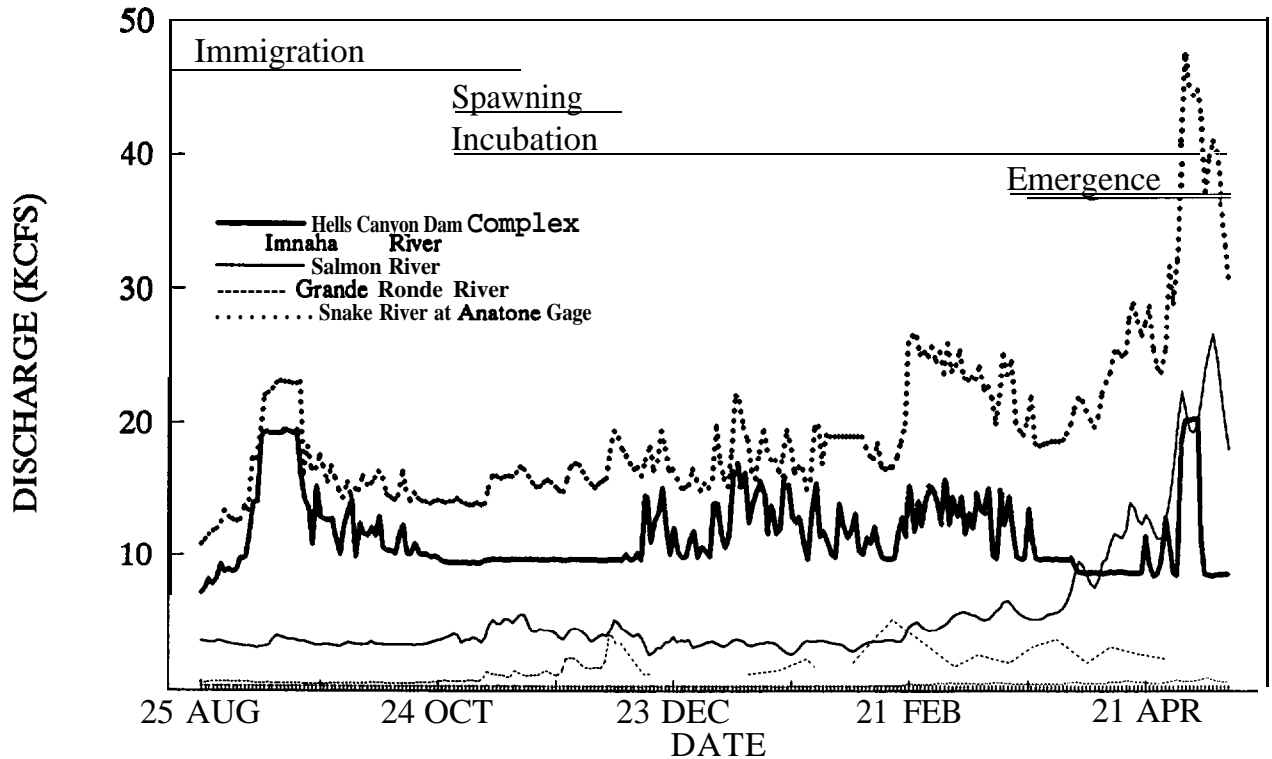
Figure 8. Average daily discharge at Hells Canyon Dam, Imnaha River, Grande Ronde River, and the main stem Snake River at **Anatone** Gage, Washington during the 1991 fall chinook **salmon** brood year. Data were provided by the United States Geological Survey.

Despite the discharge fluctuation effects of the Salmon and Grande Ronde rivers, Snake River flows at the Anatone Gage were more stable during fall chinook salmon spawning in the 1991 brood year (average 15.7 ± 1.2 KCFS) than during the 1990 brood year (average 16.3 ± 1.5 KCFS) when Hells Canyon Dam Complex discharge was not being stabilized (Figure 9). The 19.5 KCFS spike that occurred on the last day of fall chinook salmon redd counts (9 December) was the result of dam operation and inflated the standard deviation around the 15.7 KCFS average for the 1991 brood year.
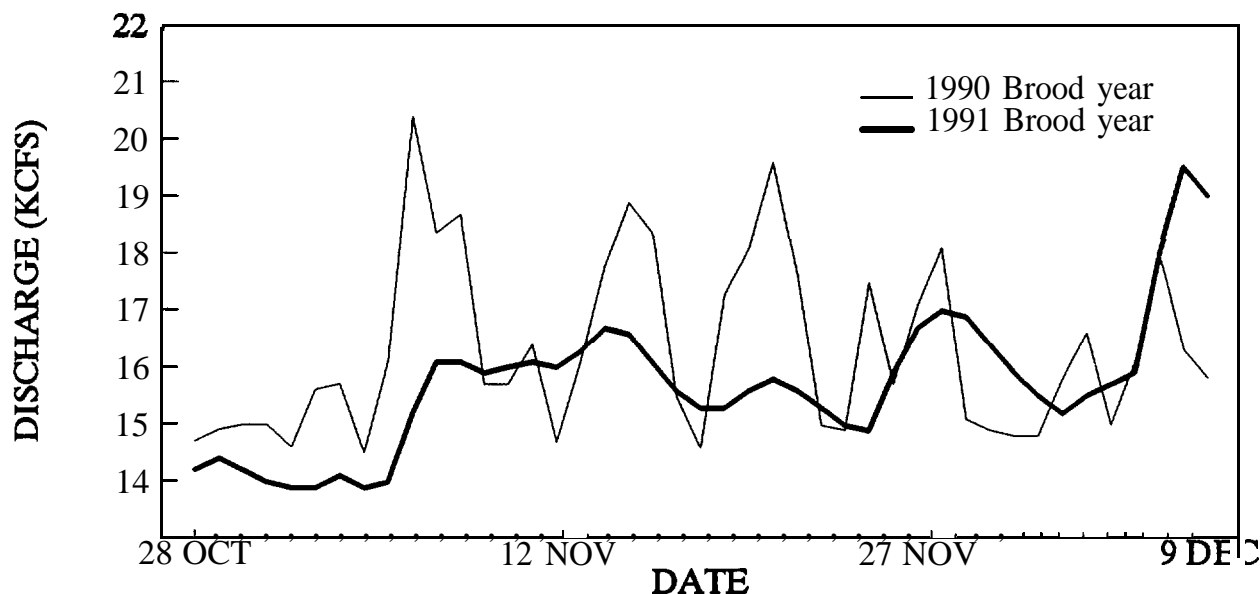
Figure 9. Snake River average daily discharge during fall chinook salmon spawning (28 October - 9 December) in 1990 and 1991. Discharge data were provided by the United States Geological Survey for Anatone Gage, Washington

Hydroelectric power peaking at the Hells Canyon Dam Complex (average 12.5 KCFS; range 9.8-17.0 KCFS) is evident from 16 December to 23 March during fall chinook salmon egg incubation (Figure 8). Hells Canyon Dam Complex shaped Snake River discharge from 16 December through 4 April. During this 118 day period, discharge at Anatone Gage fell below the highest flow (19.5 KCFS) during fall chinook salmon spawning 52% of the time. After 4 April, Salmon River discharge began increasing and supplementing Snake River discharge at Anatone Gage.

Early into the emergence period fall chinook salmon fry, on 4 April, Hells Canyon Dam Complex discharge dropped to 8.8 KCFS; 0.6 KCFS below the 9.4 KCFS average minimum discharge provided during fall chinook salmon spawning (Figure 8). Concurrently, Salmon River discharge began dropping (9.5 to 9.3 KCFS). Snake River discharge at Anatone Gage also fell slightly (22.0 to 21.8 KCFS). On 9 April, the Salmon River spring runoff began and it shaped discharge of the Snake River at Anatone Gage through peak fry emergence on 25 April. Peak discharge on the Snake River at Anatone Gage (47.2 KCFS) on 1 May was influenced by both Hells Canyon Dam Complex discharge (20.1 KCFS) and Salmon River discharge (20.9 KCFS). By 12 May, when fall chinook salmon fry emergence was ending, discharge at Anatone Gage and the Salmon River was falling towards low summer levels, but never went below the high spawning flow of 19.5 KCFS.

Snake River Water Temperatures

Snake River temperature at RK 265 (1991) during fall chinook salmon immigration and spawning (averages 16.4 + 4.2°C and 8.7 ± 1.7°C, respectively) were similar to the 1975-1982 averages (immigration average 16.0 ± 4.0°C; spawning average 8.8 ± 2.1°C; Figure 10). Water temperatures at RK 265 in 1991 were similar to the 1975-1982 averages for the first 52 d of fall chinook salmon egg incubation, but by 19 December the 1991 conditions were warmer and remained so through fry emergence.
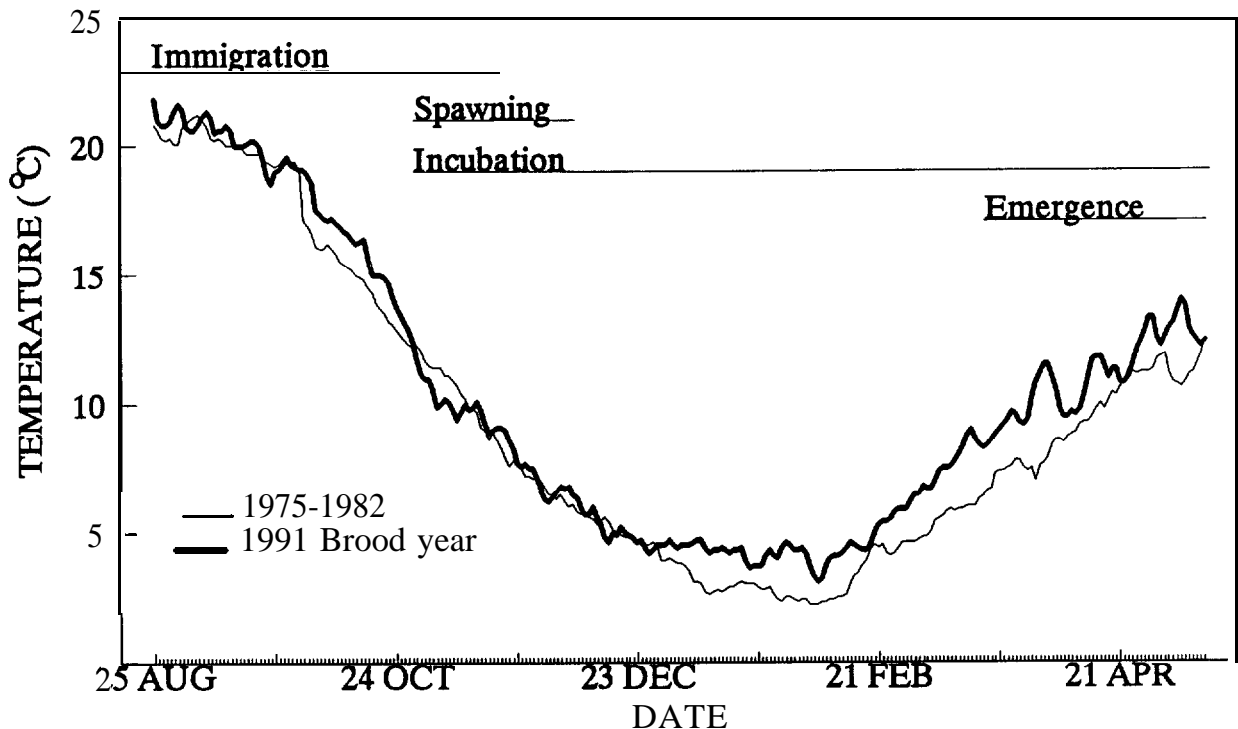
Figure 10. Average daily Snake River water temperatures for 1975-1982 and the 1991 fall chinook salmon brood year. Data were provided by the United States Geological Survey at Anatone Gage for 1975-1982 and the 1991 data were from the thermograph at RK 265.

On 25 August, the start of fall chinook salmon immigration of the 1991 brood year, average daily water temperature varied by river kilometer and was slightly cooler upriver (RK 398, 20.4°C; RK 265, 21.8°C; Figure 11). By 27 August, water temperature at all river kilometers was about 20°C. On 15 September, two separate thermal regimes formed again, only upriver temperatures were warmer than downriver temperatures. On 18 November, the water temperatures at RK 398 and RK 265 were 11.1°C and 9.1°C.

On 28 October, when the first fall chinook salmon redd was counted in the 1991 brood year, water temperature was warmer upriver than downriver (RK 398 15.7°C; RK 265 12.4°C; Figure 12). On the peak date of fall chinook redd counts (18 November) upriver temperatures were over 2°C higher than those downriver (RK 398 11.1°C; RK 265 9.1°C). Upriver water temperature remained higher than downriver water temperature through spawning and early incubation until 5 February when temperatures became higher downriver (Figure 13). Water temperature did not go below freezing at any main stem Snake River thermograph location during fall chinook egg incubation of the 1991 brood year.

Daily average water temperatures and trends of the Imnaha, Salmon, and Grande Ronde Rivers were similar to each other through the 1991 fall chinook salmon brood year (Figure 14). The most obvious difference was the greater stability of the Salmon River temperature regime. Temperatures in all three tributaries exceeded 22.0°C during adult fall chinook salmon immigration and declined below 0.5°C during egg incubation.

Daily average Hells Canyon air temperature (RK 398) measured 14 d prior to Hells Canyon Dam Complex outflow temperature (RK 398) explained 89% of the variation in the dam's outflow temperature during fall chinook salmon immigration (25 August - 18 November, 1991; Figure 15). Air temperature measured 30 d before Hells Canyon Dam Complex outflow temperature explained 81% and 83% of the variation in the dam's outflow temperature during fall chinook salmon spawning (28 October - 9 December) and early egg incubation (28 October, 1991 - 5 February, 1992). Air temperature measured 21 d prior to Hells Canyon Dam Complex outflow temperature explained 68% of the variation in the dam's outflow temperature during late fall chinook salmon egg incubation (5 February - 12 May, 1992).
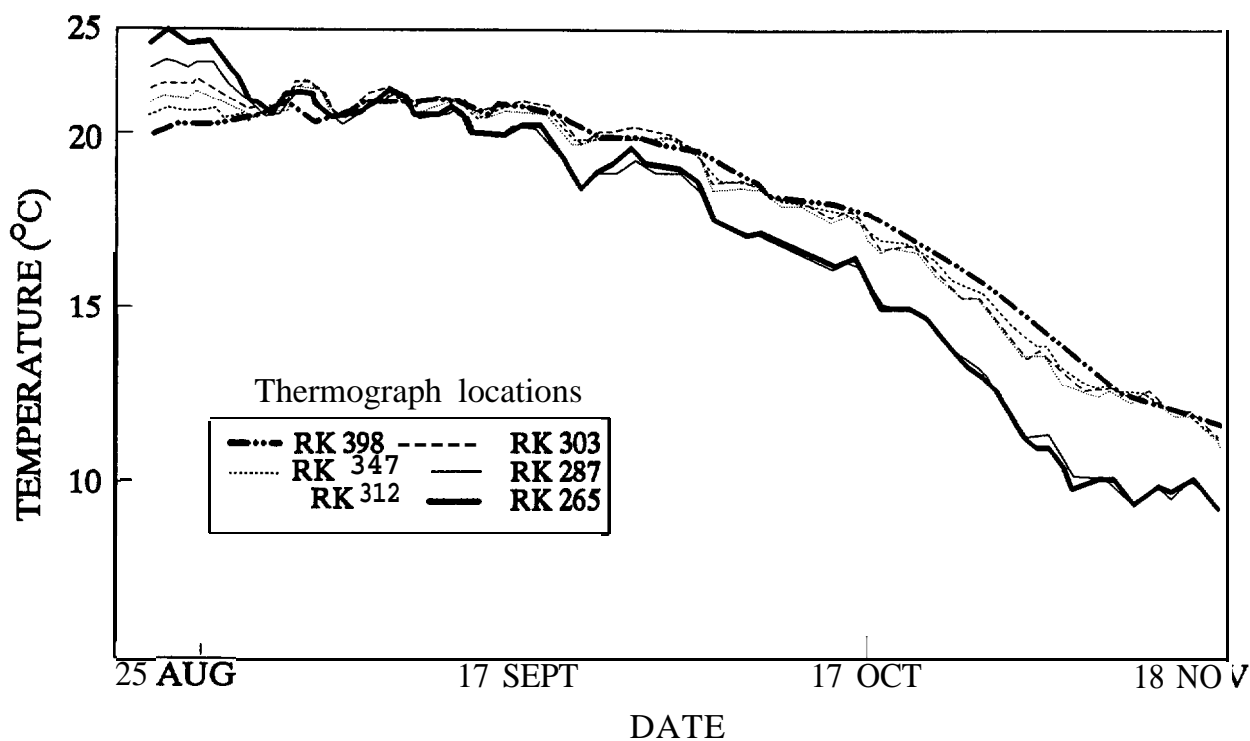
Figure 11. Snake River daily average water temperatures by river kilometer during fall chinook salmon immigration, 25 August - 18 November, 1991.
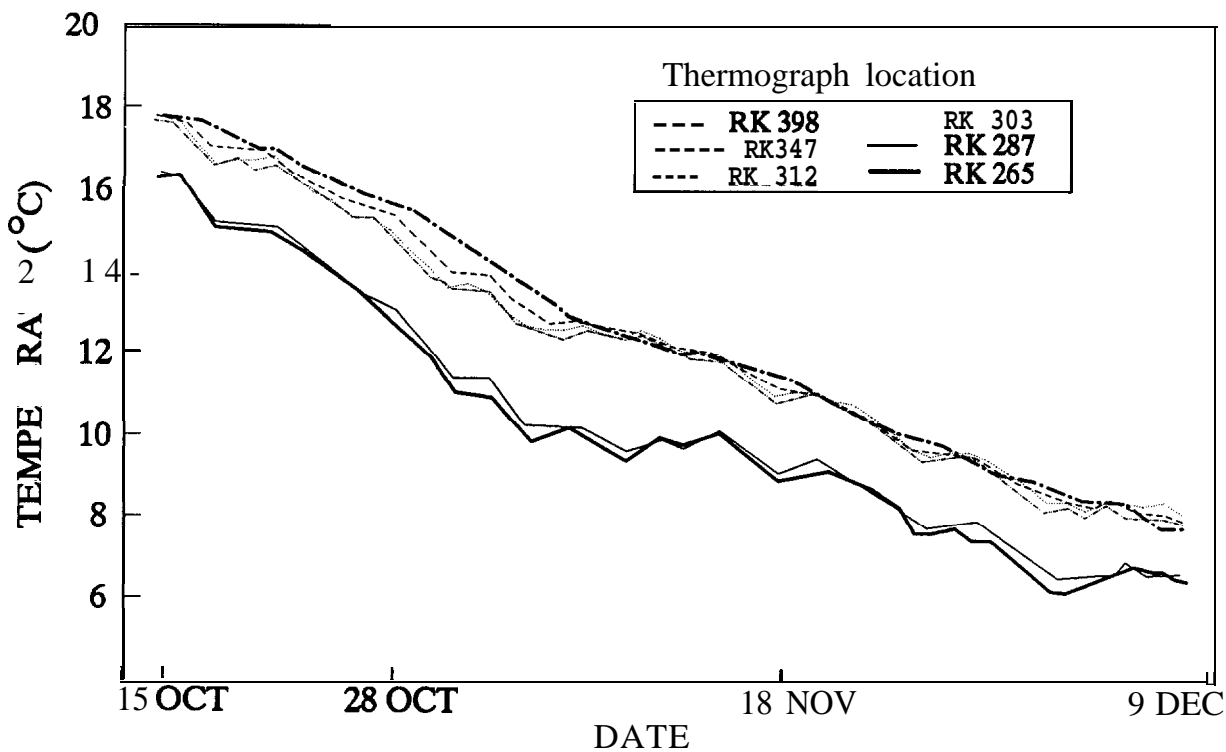
Figure 12. Snake River daily average water temperatures by river kilometer during fall chinook salmon spawning, 28 October - 9 December, 1991.
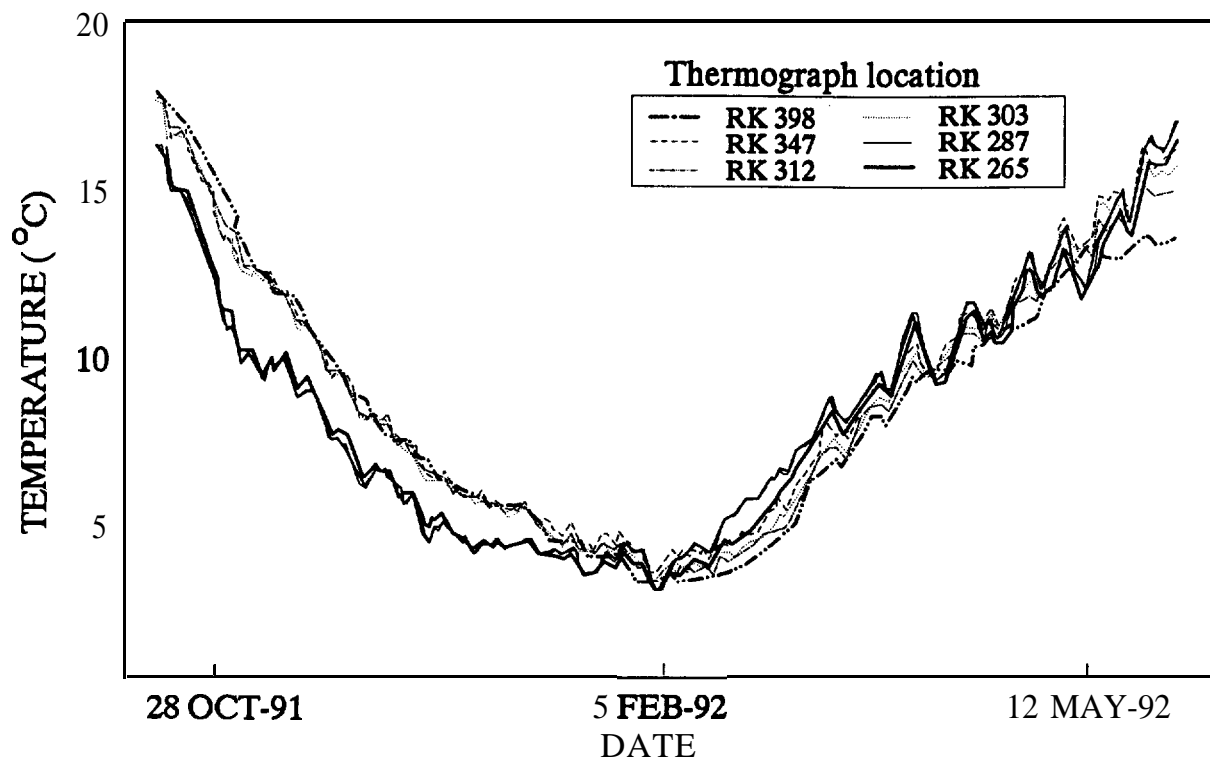
Figure 13. Snake River daily average water temperatures by river kilometer during fall chinook salmon egg incubation, 28 October 1991 - 12 May 1992.
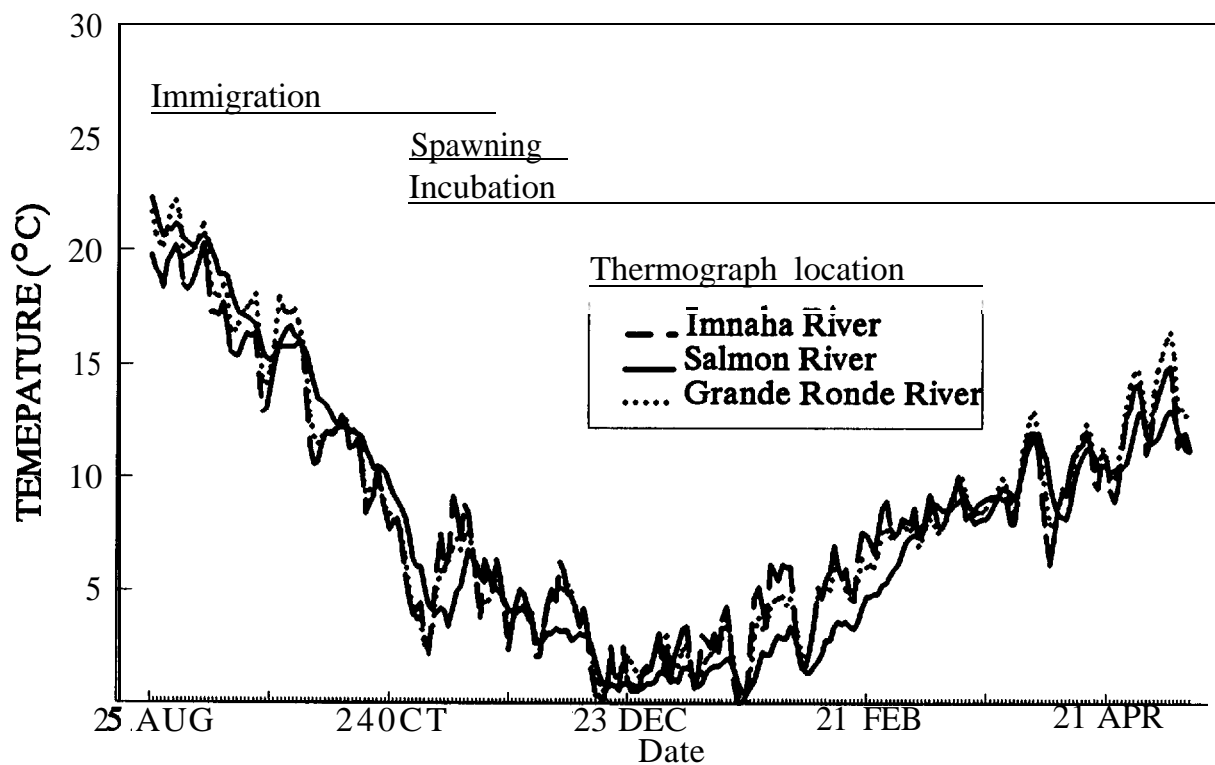
Figure. 14. Average daily water temperatures collected by thermograph in the Imnaha River, Salmon River, and Grande Ronde River, 25 August - 1991 to 12 May - 1992. Reference is made at the top of the figure to the fall chinook salmon life cycle in the Snake River, 1991 brood year.
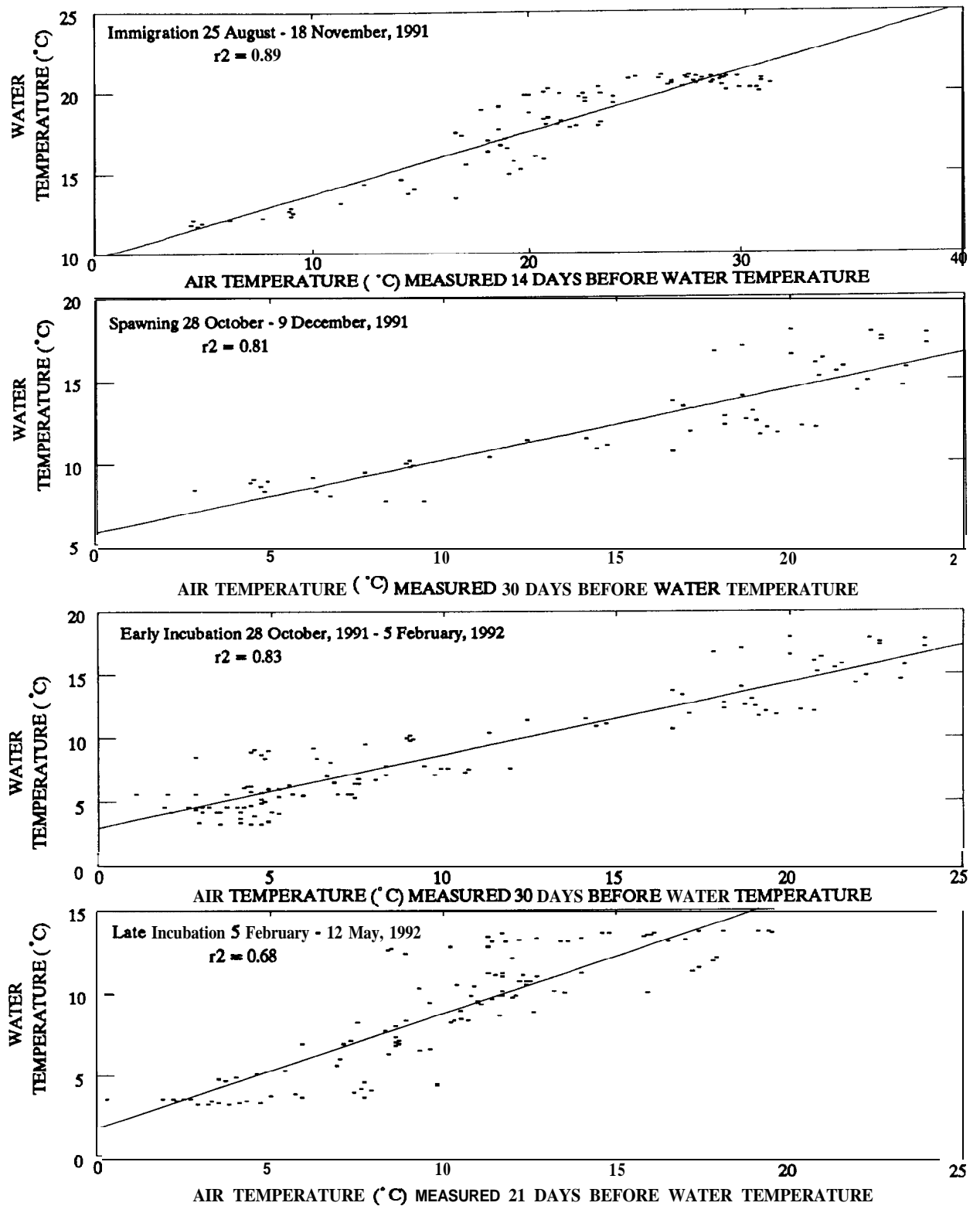
Figure 15. Relationships between Hells Canyon Dam outflow temperature and Hells Canyon air temperature at RK 398 (measured 14 to 30 **d** before water temperature) during the 1991 fall chinook salmon brood year.

Daily average water temperature at RK 312 regressed on air temperature of Hells Canyon (RK 398) and Hells Canyon Dam Complex outflow temperatures (RK 398) showed that dam outflow temperature is the significant determinant of Snake River water temperature upstream of the Imnaha River (river mouth at RK 308; Table 5). During all fall chinook life stages in the 1991 brood year, dam outflow temperature (standardized coefficients 0.828 to 0.956) affected RK 312 water temperature more than air temperature (standardized coefficients 0.079 to 0.188). The R^2 value for this relation ranged from 0.993 to 0.997 at the 0.0001 level of significance.

Table 5. SYSTAT Multivariate General linear Hypothesis test results for relations among daily average temperature of Snake River uater at RK 312, Hells Canyon air at RK 398, and Hells Canyon Dam outflou RK 398. Data were collected over the 1991 fall chinook salmon brood year.

Life stage	Dates	Temperature variable	Standardized coefficient	T-value	P-value	R^2
Immigration	25 Aug - 18 Nov-91	Air	0.188	13.939	0.000	0.997
		Dam outflow	0.828	61.337		
Spawning	28 Oct - 9 Dec-91	Air minus 30 d	0.165	3.623	0.000	0.984
		Dam outflow	0.841	18.456		
Early incubation	28 Oct-91 - 5 Feb-92	Air	0.044	2.106	0.000	0.993
		Dam outflow	0.956	46.165		
Late incubation	5 Feb - 12 May-92	Air minus 30 d	0.079	7.447	0.000	0.996
		Dam outflow	0.934	88.105		

Daily average water temperature at RK 265 regressed on air temperature of Hells Canyon (RK 398), Hells Canyon Dam Complex outflow temperature (RK 398), Imnaha River (RK 308), Salmon River (RK 302), and Grande Ronde River (RK 271) water temperatures showed that dam outflow temperature is a significant determinant of Snake River water temperature downstream of the Grande Ronde River (Table 6). During all fall chinook salmon life stages in the 1991 brood year dam outflow temperature (standardized coefficients 0.448 to 0.833) affected RK 265 water temperature more than any other temperature variable. The R^2 value for this relation ranged from 0.991 to 0.998 at the 0.0001 level of significance.

Table 6. SYSTAT Multivariate General Linear Hypothesis test results for relations among average daily temperatures of Snake River uater at RK 265, Hells Canyon air at RK 398, Hells Canyon Dam outflow at RK 398, Imnaha River water, Salmon River water, and Grande Ronde River uater. Data were collected over the 1991 fall chinook salmon brood year.

Life stage	Dates	Temperature variable	Standardized coefficient	T-value	P-value	R^2
Immigration	25 Aug - 18 Nov-91	Air	0.058	2.484	0.000	0.998
		Dam outflow	0.591	33.706		
		Imnaha River	0.107	1.902		
		Salmon River	0.170	5.186		
		G. Ronde River	0.097	1.354		
Spawning	28 Oct - 9 Dec-91	Air minus 7 d	0.032	0.835	0.000	0.991
		Dam outflow	0.833	32.828		
		Imnaha River	0.109	2.656		
		Salmon River	0.127	2.551		
		G. Ronde River	0.046	1.065		
Early incubation	28 Ckt-91 - 5 Feb-92	Air minus 30 d	0.065	2.977	0.000	0.993
		Dam outflow	0.731	31.738		
		Imnaha River	0.150	5.739		
		Salmon River	0.183	8.248		
		G. Ronde River	-0.060	-1.964		
Late incubation	5 Feb - 12 May-92	Air	-0.070	-3.455	0.000	0.996
		Dam outflow	0.448	24.835		
		Imnaha River	0.023	0.643		
		Salmon River	0.315	15.673		
		G. Ronde River	0.307	6.405		

Discussion

The distribution of fall chinook salmon redds in the Snake River below the Hells Canyon Dam Complex changed during dam construction (1956-1967). Prior to the existence of Hells Canyon Dam Complex, fall chinook salmon were rarely reported spawning in what now remains of the free-flowing Snake River between RK 398 and RK 235 (Irving and Bjornn 1981b; Witty 1988). Perhaps if spawning occurred there, it may have been undetected because of the inaccessible nature of Hells Canyon. Immediately after Hells Canyon Dam Complex was completed (1967), fall chinook salmon spawning was observed primarily in the upper third of the Snake River below the dam. Based on index counts since 1987, more than 50% of redds were counted in the lower 23% of the free-flowing Snake River. This disproportionate redd distribution was due, in part, to concentrated spawning at one site as was evident from 1987 to 1990 when 28% the total redd count was made at RK 245. Similarly, in 1991, 44% of the redds counted during index counts were at RK 261.

Timing of natural fall chinook salmon spawning from 1967-1991 is difficult to determine because of the inconsistent methods used in counting redds. Subjective interpretation of historic records on Snake River fall chinook salmon suggest that

spawning was predominantly a November event (Richards 1961; Haas 1965; Irving and Bjornn 1981b; Witty 1988). In 1991, fall chinook salmon spawning in the Snake River began in late October, peaked in mid-November, and ended by the second week in December. Increasing the understanding of the timing and duration of fall chinook salmon spawning should lead to the prevention of redd dewatering prior to fry emergence by providing more accurate starting dates for egg incubation timing estimates (Connor et al. in this report).

Counts of fall chinook salmon redds since 1987 have been consistently less than expected when compared to the numbers of fall chinook salmon passing Lower Granite Dam (RK 173; the last check point for immigrating adults). The ratio of adult fall chinook salmon passing the dam, to redds enumerated by index counts of the Snake River and aerial surveys of its tributaries above Lower Granite Reservoir has ranged from 16.0 to 1 in 1991 to 7.3 to 1 in 1990 (Seidel et al. 1988; Bugert et al. 1989-1991; Bugert 1991; Mendel et al. 1992). In 1991 we attempted to account for the above descrepancy by refining the redd counting technique. Refinement included weekly counts, ground truthing and deep-water counts. We found that the traditional approach of three index counts by helicopter under represented the minimum number of redds at RK 261 by 25%. If we expand the the 1987-1991 index counts by a factor of 0.25 the adult fall chinook salmon dam count to redd ratio still exceeds 5.8 to 1. Mendel et al. (1992) documented the fallback of radio tagged fall chinook salmon over all four of the Snake River dams in 1991. Of the seven fish tagged at Ice Harbor Dam that crossed Lower Granite Dam only one remained above the dam to spawn. Of the 15 radio tagged fall chinook salmon that crossed Lower Granite Dam, 53.3% (eight fish) fell back. Fallback of fall chinook salmon at Lower Granite Dam and undetected redds in the Snake River may explain the high adult-to-redd ratios.

While it is known that the decline in wild Snake River fall chinook salmon numbers that started in 1957 is due in part to loss of spawning habitat (Haas 1965), there is no data on how much habitat remains in the 163 km of free-flowing Snake River in 1991. At RK 261, and other sites in the Hells Canyon reach, we found salmon spawning in areas with physical characteristics typical of spawning sites used by fall chinook salmon in reaches of the Columbia River and its tributaries (Burner 1951; Chambers et al. 1956; Huntington and Buell 1985; Hampton 1988; Swan et al. 1989; Arnsberg et al. 1992). At RK 261, and all other spawning sites we studied in 1991, there was considerably more area available for spawning than was utilized by fall chinook salmon.

Discharge during the 1991 fall chinook salmon brood year was considerably lower than for the 20 year period after of the completion of the Hells Canyon Dam Complex. Under drought conditions the operation of Hells Canyon Dam Complex shapes the

flow regime of the Snake River as far downstream as the Anatone Gage at RK 270. Consequently the attempt by Idaho Power Company (IPCo) to prevent fall chinook salmon redd dewatering between Hells Canyon Dam and the mouth of the Salmon River (RK 302; Idaho Power Company 1991) appears to have had positive effects as far downriver as Anatone Gage (RK 270). However, the premature increase of flows on the last day of fall chinook salmon redd counts (9 December) may have provided some December spawning fish with habitat destined for dewatering during subsequent hydroelectric power peaking operations. Likewise, IPCo reduced the flows from their 9.4 KCFS minimum on 4 April prior to the completion of fall chinook salmon fry emergence. As expected, Salmon River discharge was increasing and there is no evidence of any fall chinook salmon redd dewatering in the free-flowing Snake River in 1991.

When comparing Snake River water temperatures during the 1991 fall chinook salmon brood year to the limited post-Hells Canyon Complex data set, we found differences we suspect are wholly or partially attributable to drought conditions from 1987 through 1991. Temperature data indicate the temperature of Hells Canyon Dam Complex outflow was influenced by air temperature recorded 14 to 30 d prior to the time of flow release. In turn, the temperature of the water released from the Hells Canyon Dam Complex controlled the Snake River's temperature regime downstream as far as RK 265. These results, although preliminary, emphasize the importance of examining water temperature when studying fall chinook salmon life history in regulated river systems.

In recent years, warm water conditions during Snake River fall chinook salmon immigration have stimulated much debate, especially with regards to the existence of a thermal block below Ice Harbor Dam (RK 15) and the need for water temperature control efforts in the Snake River (Chapman 1991; Vigg and Watkins 1991). Karr et al. (1992) made flow-based water temperature control recommendations which were implemented at Dworshak and Brownlee Dams. Karr and his colleagues are collecting additional data and refining their models to make a conclusive assessment of the benefits of this temperature control on adult immigration conditions.

In conclusion, our findings during 1991 indicate: (1) the number of fall chinook salmon redds counted during the first two index counts of the free-flowing Snake River dropped from 66 in 1987 to 31 in 1991; (2) fall chinook salmon spawn throughout the remaining free-flowing Snake River and concentrated spawning at one site is common: (3) fall chinook salmon spawning is mainly a mid-November event, but limited spawning occurs in late October and early December: (4) redd counts in the past have been inaccurate, but even after refining counting techniques the total number of fall chinook redds found in the free-flowing Snake

River in 1991 was critically low; (5) typical fall chinook salmon spawning habitat appears relatively abundant in the remaining 163 km of the free flowing Snake River, but it is dramatically underseeded; and, (6) Hells Canyon Dam Complex affects Snake River discharge and water temperature throughout the remaining 163 km of free-flowing river, but these effects have not yet been measured adequately for specific recovery planning and judicious water management. Finally, most of the information we have presented in this chapter was collected under the drought conditions of 1991 and will likely be modified upon the analysis of additional data.

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CHAPTER TWO

Swimming Behavior of Subyearling Chinook Salmon

by

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Introduction

Providing adequate flows in the Columbia and Snake rivers to ensure the timely downstream migration of juvenile Pacific salmonids *Oncorhynchus* spp. is an acknowledged requirement for increasing their survival. However, the magnitude and timing of the flows required is subject to considerable debate. Developing a better understanding of the migratory behavior of juvenile salmonids, and the factors directing and regulating this behavior, is required to operate the hydropower system in the most efficient manner to ensure juvenile salmonid survival.

Relatively little is known, particularly for juvenile chinook salmon 0. *tshawytscha*, about the factors directing and regulating their seaward migration. The timing of juvenile salmon emigration is dependent upon their physiological readiness to adapt to saltwater, but environmental stimuli (e.g., water current, temperature, photoperiod) may direct or trigger migration and regulate the rate of migration (Northcote 1984). Most salmonid species in the Columbia River basin initiate their seaward migration in the spring of their second year of life, but some summer and all fall races of chinook salmon compress their freshwater rearing and migratory stages into their first summer of life.

Considerable debate has occurred in the scientific literature on whether the migration of juvenile salmon is active or passive (see review by Jonsson 1991). Some component of the migration must be active (e.g., the movement of fish out of backwaters, sockeye salmon 0. *nerka* movement out of a lake) before fish would be subject to passive drift by the current, the most efficient migratory mode in terms of bioenergetics (Tytler et al. 1978; Thorpe et al. 1981). There is, however, general agreement in the literature that migration occurs primarily at night except when the water is turbid, in extreme northern latitudes, or during the peak of migration (Jonsson 1991).

Laboratory experiments on hatchery reared Atlantic salmon *Salmo salar* (McCleave and Stred 1975) and coho salmon 0. *kisutch* (Flagg and Smith 1982) documented a decline in swimming performance from about eight to two body lengths per second (bl/s) as the juveniles underwent the parr-smolt transformation. This decrease in performance in conjunction with interpretation of observed migration rates led Smith (1982) to develop the paradigm that in the Columbia River, yearling salmonids must migrate during only part of a day by swimming upstream at up to 2 bl/s. Observed migrations of yearling chinook salmon migration tend to support

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this paradigm as the smolt travel times were less than that estimated by water particle travel time; migration rates were primarily dependent upon water velocities, and secondarily upon smolt development, especially early in the migration (Raymond 1968; Beeman et al. 1991; Berggren and Filardo, in press).

No similar paradigm has been proposed to describe the migration of subyearling chinook salmon. The fact that these fish rear in, as well as migrate through, Columbia and Snake river reservoirs confounds attempts to characterize by field studies the environmental and biological stimuli which direct and regulate their seaward migration. Therefore, this laboratory study was designed with the objectives of determining whether subyearling chinook salmon emigrate actively or passively, and the influence of environmental and biological factors on directing and regulating the rate of emigration.

Methods

The basic study design consisted of observing the swimming behavior of subyearling chinook salmon subjected to increasing water velocities. Hatchery and migrating fish were subjected to the test conditions bimonthly during the day and night.

Fish Collection and Maintenance

On 8 April 1991, 1,000 Bonneville pool hatchery stock subyearling chinook salmon were transferred from Little White Salmon National Fish Hatchery (NFH) to an 800 L holding tank (diameter = 122 cm, depth = 69 cm) at the Columbia River Field Station. Initial water temperature in the tank was maintained at the hatchery water temperature (7.5°C), and the water flow created a circular current in the tank. The fish were fed a diet of 1-mm commercial moist pellets until they reached a mean length of 10 cm, whereupon they were fed a 2.5-mm pellet. The feeding ration was adjusted over time to compensate for change in growth and water temperature. Fish were fed once daily five days a week.

Subyearling chinook salmon assumed to be emigrating were collected bimonthly from Bonneville Dam First Powerhouse from 2 June through 25 August 1991. We haphazardly selected 20 fish from a sample of fish passing through the dam's bypass system at the time of greatest passage, usually about sunset. The fish were transported about 40 km to the laboratory and immediately transferred into the test flume to be used in a swimming trial. Fish collected from Bonneville Dam were allowed at least 24 h to recover from the stress of collection and transportation before testing. Water velocity in the test flume during this recovery period was O-1 cm/s. Fish were not fed during this time.

Incandescent lighting illuminated the tanks, and a timer was

used to simulate the natural photoperiod until 23 April 1991. A fixed photoperiod of 0500 to 2000 hours (15 h daylight, 9 h dark) was maintained from 23 April to 30 August 1991. A fixed photoperiod was used to ensure sufficient time for the fish to be tested in darkness. After 30 August the natural photoperiod was resumed. Light intensity varied from 1-4 lumens in the day and 0.02-0.07 lumens at night.

All tanks were supplied with well water which flowed through a Watlow' 50 KW three phase single pass water heater. Water temperature in the tanks was adjusted to follow the Columbia River water temperature as it changed over time. During the testing period water temperature ranged from 5.5-20.7°C.

<u>Laboratory Set-up,</u>

The test apparatus was a 36-cm wide by 35-cm deep circular flume located at the circumference of a 366-cm diameter fiberglass tank (Figure 1). A 7.5 horsepower Paco pump connected to a Magnetek adjustable frequency drive circulated water through four sets of 1.3-cm PVC pipes containing nine openings directed into the flume. Two 48 x 122 cm areas equidistant from each other were covered to provide shade. Two sets of six black lines about 5-cm wide and 8-cm apart were painted on the flume bottom equidistant from each other to provide visual reference. A Javelin infrared sensitive camera was mounted above the flume and a Sylvania Mini-Kat indoor infrared light was used at night for illumination; 3M Scotchlite reflective tape was placed beneath the camera on the flume bottom to increase available light. A black line was painted across the reflective tape and divided into three equal sections to denote the inner, middle, and outer sections of the flume (Figure 1). This reference line was essential in counting the fish. A Burle monitor and a Javelin Heliguad II VHS record/playback machine were used to monitor and record fish behavior.

Water velocity was measured in the center of the flume with a Marsh-McBirney velocity meter. The velocity meter, monitor, and record/playback machine were located in an adjacent room to minimize disturbing the fish during testing.

<u>Experimental Protocol</u>

Identical swimming behavior trials were conducted during the day and night. The night trials began after 1 h of darkness. The fish were subjected to progressively increasing water velocities of 5, 10, 15, 20, 25, 30, 40, and 50 cm/s in a 4-h

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'Use of trade names does not imply endorsement by the U. S. Fish and Wildlife Service.

1-camera

2-shaded areas

3-visual orientation lines

4-reference line

5-direction of water flow

pump

to drain
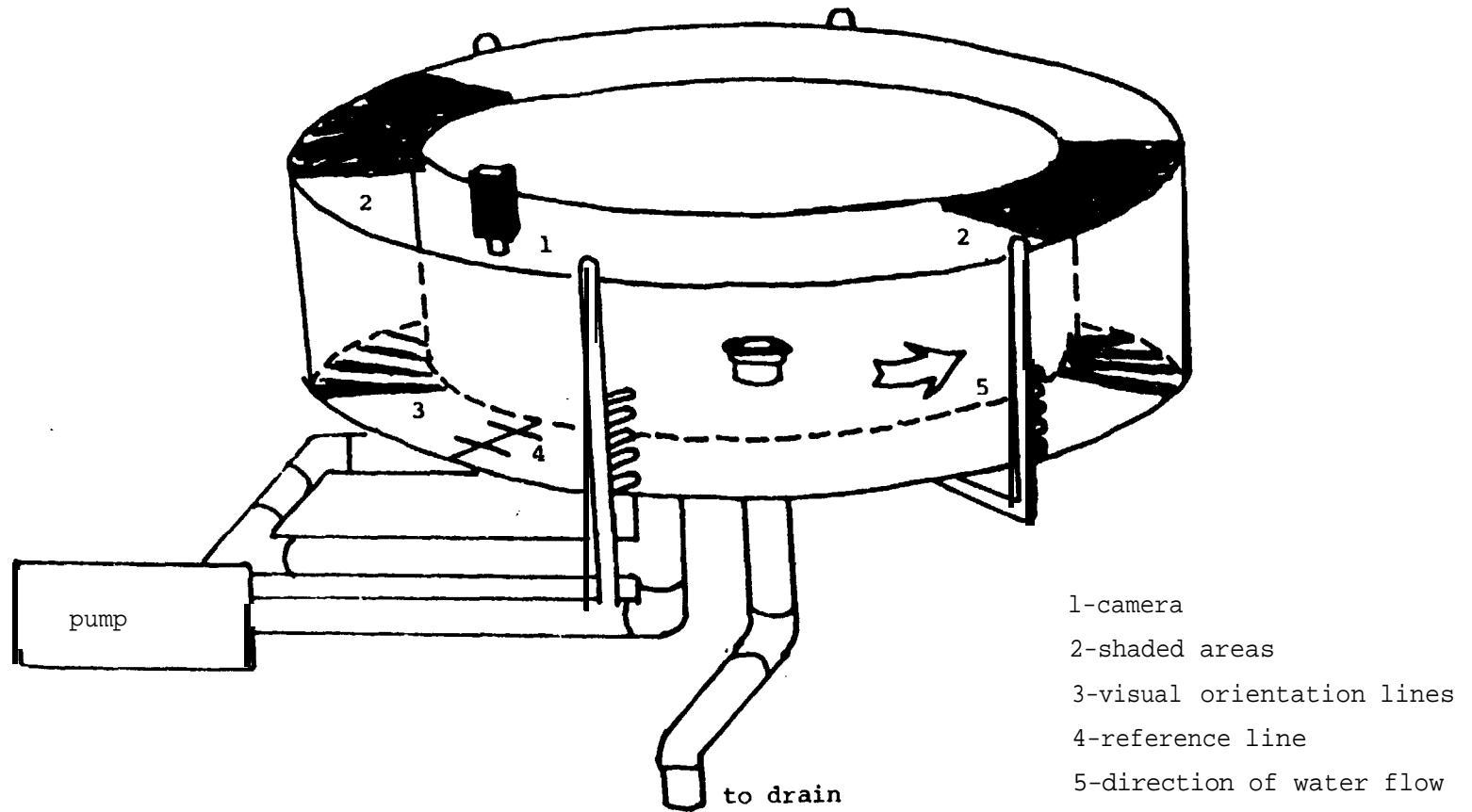
Figure 1.   A schematic representation of the experimental design: the test tank and associated plumbing.

period. Each velocity was maintained for 30 min; the first 15 min allowed the velocity to stabilize, and during the second 15 min the fish were video taped. The day trials began 8 h after completion of the night trials. Upon completing a trial the fork length, weight, and a gill sample were obtained from each fish. Gill Na^+-K^+ ATPase activity was measured according to Zaugg (1982), with minor modifications.

Data Collection and Analysis

Five randomly selected 1.5 min intervals from each 15 min taping period were used to quantify the behavior of the fish. The number of fish passing the reference line was counted. The orientation (i.e., facing upstream-positive rheotaxis, facing downstream-negative rheotaxis, passive drifting) and distribution of the fish in the flume (i.e., inner, middle, outer) were also recorded. The water velocity the fish were actually subjected to was corrected on the basis of their distribution in the flume, adjusting for the discrepancy in velocities across the flume. A difference in velocity of about 30% existed between the middle section and the inner and outer sections. The mean displacement velocity of the fish at each test velocity was calculated for each of the five counts at the eight velocities for a total of 40 observations per swimming trial. Mean swimming velocity of the fish was calculated by subtracting their displacement velocity from the water velocity. The swimming velocity of the fish was expressed in cm/s and bl/s to facilitate comparisons among different sized fish. All statistical tests were executed with STATGRAPHICS software (STSC Inc. 1989).

Two methods were used to present the results in terms of hypothetical miles traveled by a fish in a day. In the first method, the hypothetical distance traveled per day by a fish during each paired day-night series conducted was calculated as:

$$D = a\sum_{i=1}^{8} DVN_i + 2a\sum_{i=1}^{8} DVD_i$$

where D = miles traveled per day; DVN = displacement velocity (cm/s) during night trial; DVD = displacement velocity (cm/s) during day trial; a = factor to convert cm/s to miles/8 h; and i = eight water velocity (cm/s) levels. The estimate was weighted on the basis of a 16 h day and 8 h night, which approximates the June-August photoperiod, and compared with the distance which would be traveled by passive drift at the mean water velocity tested. In the second method, the hypothetical miles traveled per day at the eight water velocities tested was calculated as:

$$D_i = a(DVN_i) + 2a(DVD_i).$$

The results were then applied to John Day and Bonneville pools by
expressing the water velocities at which the fish were tested as
discharge rates at John Day and Bonneville dams which would
provide comparable water particle velocities through these
reservoirs. The appropriate discharge rate was calculated as:

$$DR = RV/(RL/b_i);$$

where DR = discharge rate in thousands of cubic feet/s (kcfs), RV
= reservoir volume (acre feet), RL = reservoir length (feet), and
b = factor to convert cm/s to ft/s.

Results

Fish obtained from Little White Salmon NFH were tested from
11 April until 10 September 1991 and migrating fish collected at
Bonneville Dam were tested from 4 June until 28 August 1991
(Table 1). The water temperature was increased from 8°C in April
to 21°C by late July where it remained during August before
declining to 20°C in September. During the course of the study,
hatchery fish increased in mean length from 5.0 to 9.6 cm and
migrants increased in mean length from 8.8 to 12.3 cm: hatchery
fish were 1.3-3.0 cm shorter than migrants for any comparable
test period (Table 1). Mean gill **ATPase** activity in hatchery
fish decreased from 11.8 **micromoles Pi·mg protein^{-1}·h^{-1}** in April
to 6.6 in July before increasing to over 18.0 in late August.
Migrants collected at Bonneville Dam exhibited mean gill **ATPase**
activities of 20.0 to 33.5, values consistently higher than
observed in hatchery fish.

Swimming Behavior

Analysis of variance indicated that the mean swimming
velocity of hatchery and migrating subyearling chinook salmon was
significantly different by date and by day and night (F > 14.867;
P < 0.01; Table 2). The mean swimming velocity required for a
fish to maintain position at the eight velocities tested was 24.4
cm/s and when corrected for fish distribution in the flume, 27.7
cm/s. The mean swimming velocity of hatchery fish decreased from
April to July before increasing as the season progressed; the
trend was more pronounced during the day than at night (Table 2).
Hatchery fish tested during the day exhibited the lowest mean
swimming velocity as a result of swimming downstream from 9 May
through 9 August. The mean swimming velocity of migrating fish
increased with time, peaking in mid-July during the day, and at
the end of the study at night. Gill **ATPase** activity and mean
swimming velocity of hatchery fish were significantly correlated
(P < 0.01) during the day and night (r = 0.886 and 0.604,
respectively) but for migrating fish were not significantly
correlated (P > 0.05; r < 0.323).

Swimming velocity was regressed on water velocities for time
periods which were similar according to Tukey's test of the means
(Table 2; Figures 2 and 3). The coefficients of determination

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Table 1. Date and water temperature (T) when experiments were conducted and the number (N), fork length (FL), weight (WT), gill ATPase activity, and associated standard errors for subyearling chinook salmon used in the experiments.

DATE	T(°C)	N	HATCHERY FISH FL(cm)	WT(G)	ATPase	N	MIGRANTS FL(cm)	WT(g)	ATPase
April 11, 12	8	19	5.0±0.08	1.1±0.05	11.8±1.21				
April 25, 26	8	12[a]	5.1±0.13	1.3±0.10	8.3±1.04				
May 9, 10	10	22	5.9±0.11	2.1±0.11	9.4±0.92				
May 23, 24	11	20	6.4±0.11	2.6±0.14	6.8±0.48				
June 4-7	13	20	6.8±0.17	3.0±0.18	7.4±0.47	18	9.7±0.12	8.0±0.40	
June 18-21	14	20	6.9±0.11	3.3±0.15	8.0±0.36	20	9.1±0.24	7.4±0.56	23.2±2.52
July 2-5	16	20	7.5±0.15	4.0±0.20	7.2±0.44	20	8.8±0.21	6.4±0.54	21.4±1.78
July 16-19	19	20	7.7±0.14	4.3±0.25	6.6±0.35	21	10.6±0.19	11.9±0.73	33.5±2.24
July 30, 31	21					21	10.4±0.26	11.8±0.90	32.5±1.47
Aug 8, 9	21	20	8.4±0.11	6.1±0.29	10.9±0.60				
Aug 13-16	21	20	8.7±0.12	7.0±0.30	13.1±0.63	19	11.3±0.41	15.5±1.50	20.0±1.04
Aug 27-30	21	20	9.3±0.13	8.6±0.41	18.8±0.93	20	12.3±0.16	19.6±0.80	26.6±2.00
Sept 9, 10	20	20	9.6±0.16	9.2±0.51	18.4±1.38				

[a] Eight of the original twenty fish in the test escaped from the flume into the center of the tank between the day and the night series.

Table 2. Mean swimming velocity (cm/s) during each test series of hatchery and actively migrating subyearling chinook salmon. Mean values within a column followed by the same letter are not significantly different (P < 0.01) by Tukey's test.

DATE	HATCHERY FISH		MIGRANTS	
	DAY	NIGHT	DAY	NIGHT
April 11, 12	19.2d	14.9d		
April 25, 26	13.3d	13.8d		
May 9, 10	-4.8c	5.6abc		
May 23, 24	-3.6c	3.7ab		
June 4-7	-11.4c	2.1ab	15.6a	5.6a
June 18-21	-14.6bc	2.1ab	15.7a	11.9ab
July 2-5	-21.8ab	1.8a	38.0b	19.9cd
July 16-21	-28.4a	8.4abcd	43.1b	19.0bc
July 30-31			38.0b	19.8cd
August 8, 9	-13.3bc	12.2cd		
August 13-16	21.3d	8.9abcd	39.6b	21.3cd
August 27-30	42.8e	15.0d	31.0b	27.3d
Sept. 9, 10	40.2e	10.1bcd		
MEAN	3.2	8.2	31.6	17.0
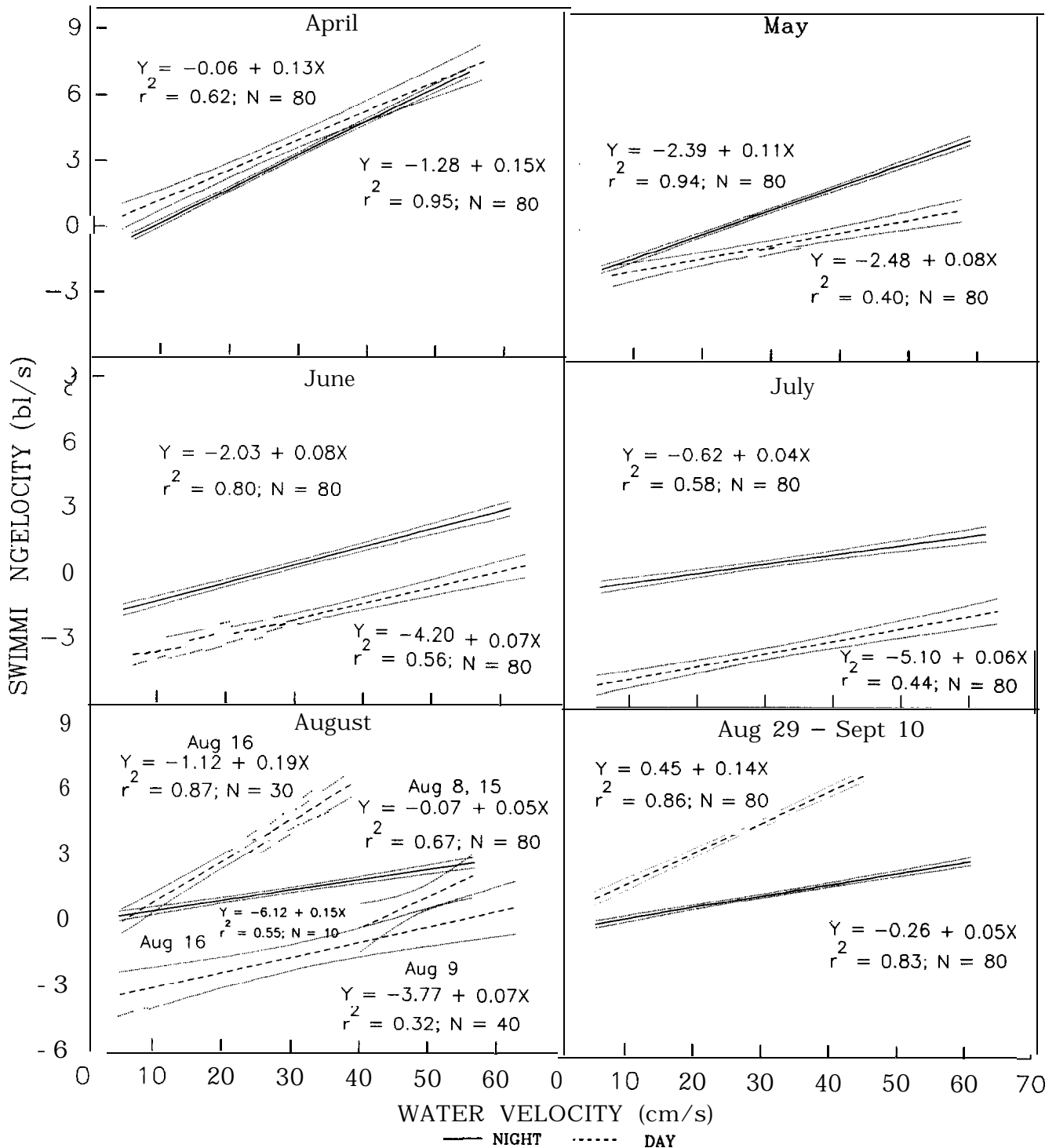
Figure 2. -Linear regression lines with 95% confidence limits of the swimming velocity (bl/s) of subyearling chinook salmon from Little White Salmon NFH versus water velocity (cm/s) by month and time of day tested.
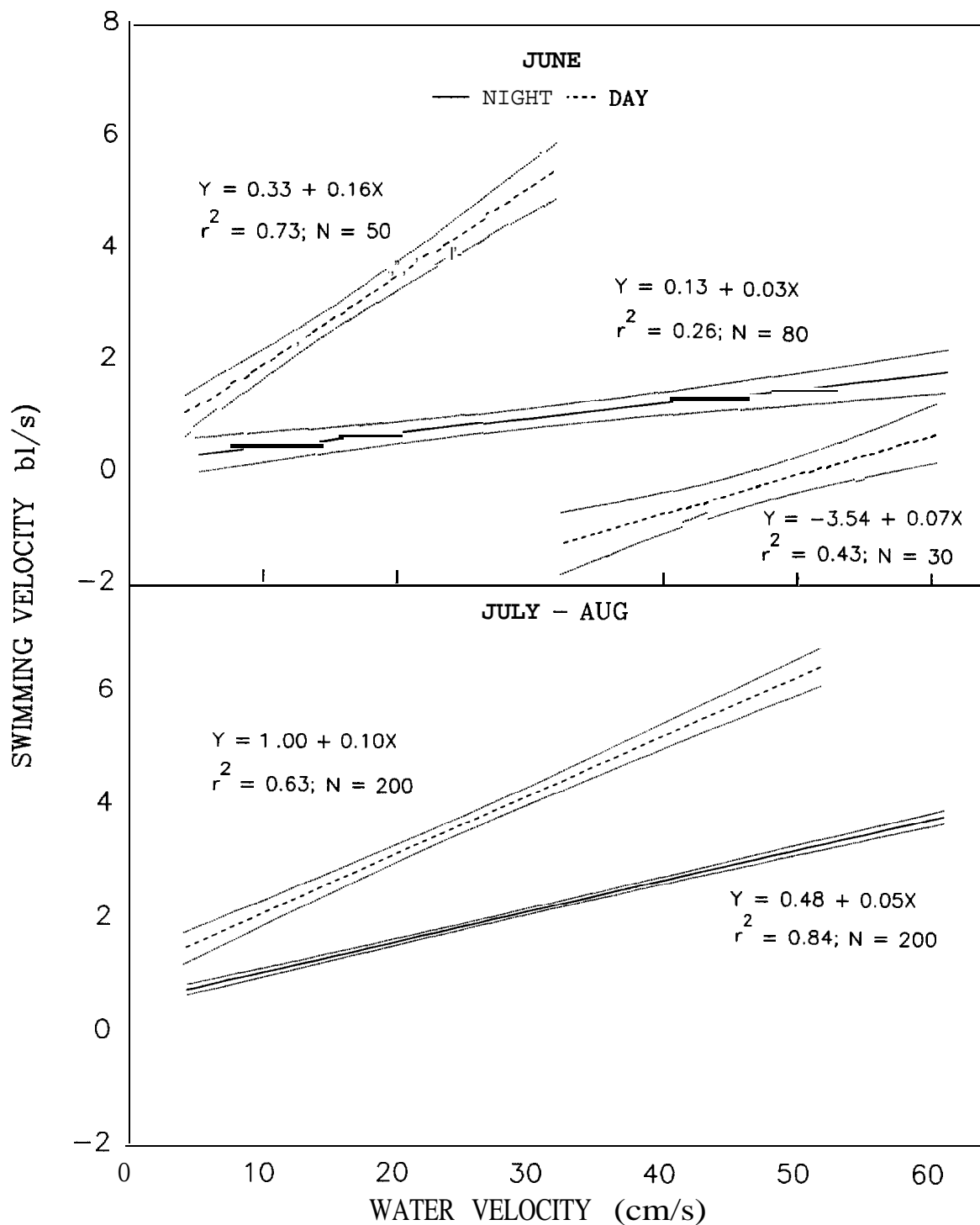
Figure 3.-Linear regression lines with 95% confidence limits of the swimming velocity (bl/s) of subyearling chinook salmon collected at Bonneville Dam versus water velocity (cm/s) by month and time of day tested, 1991.

ranged from r^2 = 0.319 to 0.955 (P < 0.01) for hatchery fish and
r^2 = 0.262 to 0.842 (P < 0.01) for migrants. For hatchery fish
the slopes of all regressions were similar but the intercepts
declined from April through July before increasing in August and
September (Figure 2). The trend was the same for fish tested
during the day and night but the changes in intercept were not as
extreme during the night as during the day. During May, June,
and July hatchery fish swam downstream during the day when water
velocities were less than 40 cm/s and during the night when water
velocities were less than about 20 cm/s (Figure 2). Hatchery
fish tested during the day on August 16 changed from swimming
upstream at rates exceeding the test water velocities to
passively drifting, or slightly swimming upstream, when the water
velocities approached 40 cm/s. In the remaining periods the
hatchery fish swam upstream at velocities only slightly less than
the test water velocity, thereby remaining nearly stationary.

     In June, migrating fish changed their swimming behavior
during the day as the water velocity increased (Figure 3). These
fish swam upstream at mean velocities exceeding 4 bl/s when water
velocities were less than 30 cm/s and then changed to swimming
downstream at mean velocities of 0 to -2 bl/s when water
velocities exceeded 30 cm/s. During the night these fish
exhibited mean swimming velocities that rarely exceeded 2 bl/s.
Mean swimming velocities of the migrants during July and August
exceeded 6 bl/s during the day and 4 bl/s at night.

     The mean day and night maximum swimming velocity observed
during each trial was highest for the smallest fish (Figure 4).
The mean maximum swimming velocity declined from over 7 bl/s for
hatchery fish 5.1 cm in length to near zero for hatchery fish 7.7
cm in length. The mean maximum swimming velocity then increased
to about 4 bl/s where it remained for migrating and hatchery fish
9-12 cm in length. Although hatchery and migrating fish
exceeding 8.5 cm in length were tested 6 to 8 weeks apart, their
maximum swimming velocities differed by less than 1.5 bl/s.
Maximum swimming velocity of hatchery and migrating fish was not
significantly correlated with their gill ATPase activity (P >
0.05; r < 0.451).   The hypothetical number of miles a hatchery
fish would be displaced per day at a water velocity of 27.7 cm/s,
the mean velocity at which they were tested, increased from April
to early July followed by a decrease to September when the fish
would move slightly upstream (Figure 5). The hypothetical
distance hatchery fish would be displaced during June and July
exceeded the distance they would be displaced by passive drift
because they swam downstream in the flume during the day.
Migrants would hypothetically be displaced only during June and
might exhibit upstream movement, albeit minimal, during July and
August at mean water velocities less than 27.7 cm/s.

     The hypothetical miles traveled per day in John Day and
Bonneville reservoirs were estimated only for June when migrants
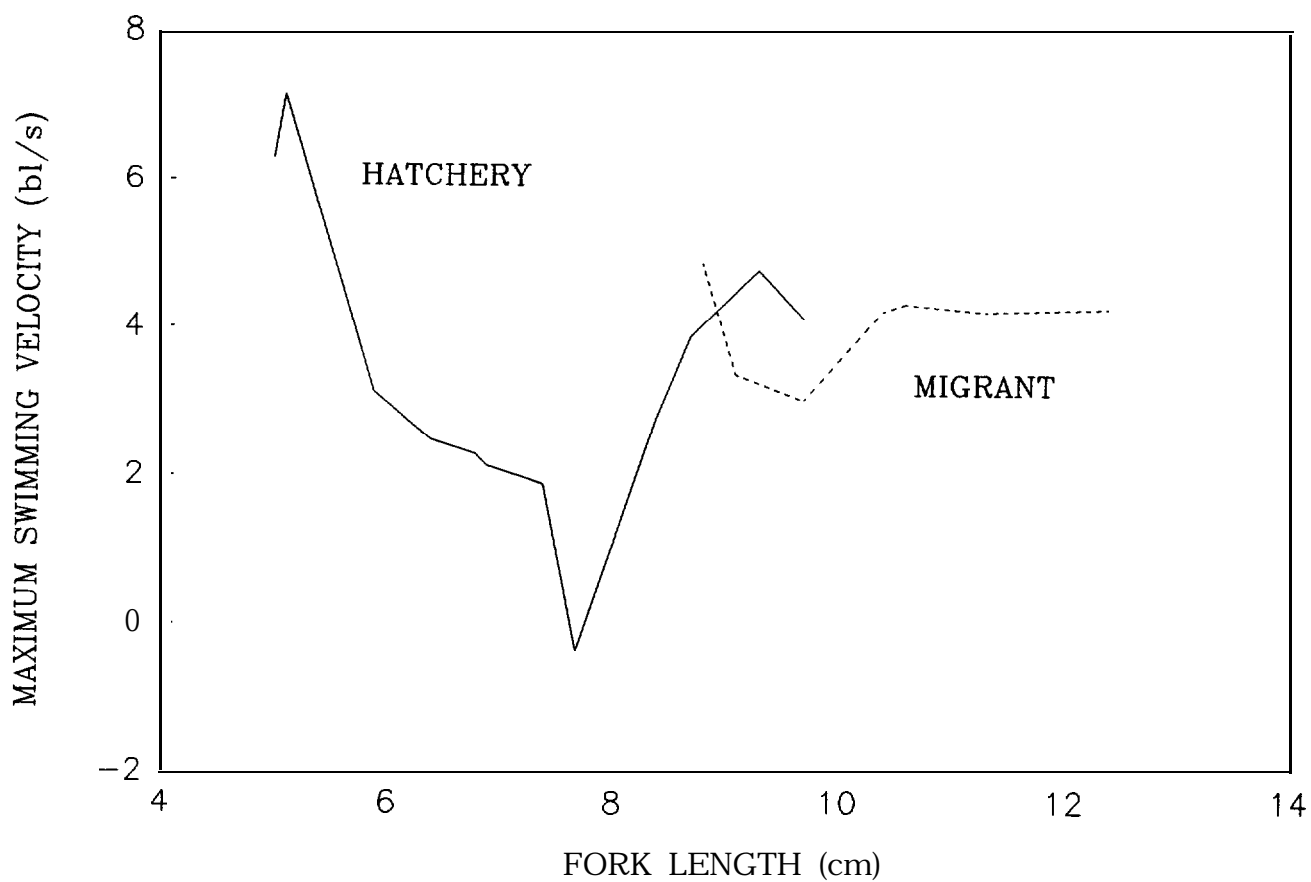
Figure 4.—Maximum swimming velocity (bl/s) of subyearling chinook salmon from Little White Salmon NFH and migrating fish from Bonneville Dam by mean fork length (cm), 1991.
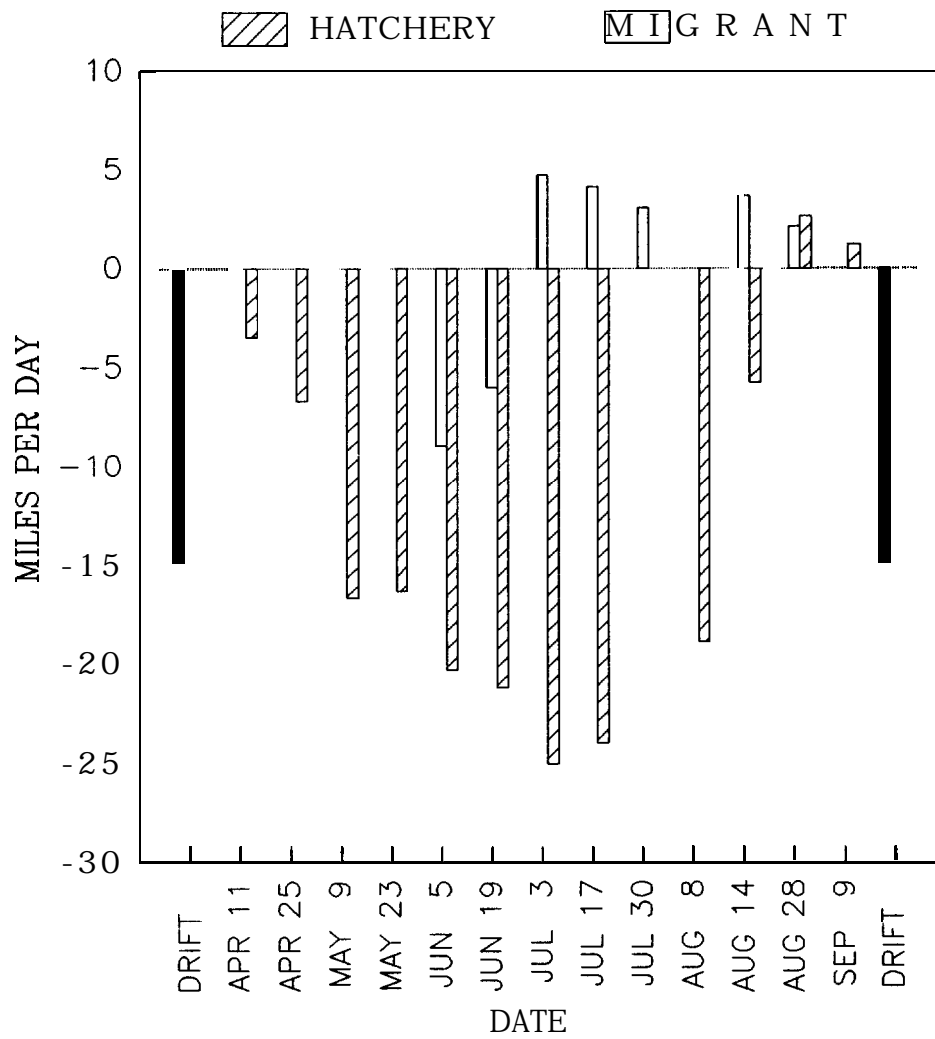
Figure 5.—Hypothetical miles traveled per day by sub-yearling chinook salmon from Little White Salmon NFH and migrating fish from Bonneville Dam during each test series when exposed to a mean water velocity of 27.7 cm/s.

exhibited their maximum disposition to migrate (Figures 3 and 5). The distance hatchery fish would be displaced increased in proportion to increased flows until discharges reached about 80 kcfs and 225 kcfs at Bonneville and John Day dams, respectively, after which the distance displaced stabilized as flows increased (Figure 6). For migrating fish, the change observed in their swimming behavior from positive to negative rheotaxis at water velocities of 25-30 cm/s had a pronounced affect on the hypothetical distance they would travel in a day at different discharge rates. Migrating fish would not be displaced downstream until flows exceeded about 80 kcfs at Bonneville Dam and not until flows exceeded 225 kcfs at John Day Dam.

<u>Orientation and Distribution</u>

Each possible orientation of the hatchery fish in the test flume was significantly different from each other (t > 3.265; P < 0.01; Figure 7) as were those of migrants (t > 4.349: P < 0.01). The predominant orientation of hatchery fish was negative rheotaxis, whereas the predominant orientation of actively migrating fish was positive rheotaxis. Negative rheotaxis in hatchery fish predominated from May-July and until water velocities exceeded 30 cm/s. Hatchery and migrating fish rarely drifted passively in the flume.

Significantly more hatchery and migrating fish were distributed in the outer section of the flume than in the middle or inner sections (t > 3.797: P < 0.01). The proportion of hatchery fish in the outer section was lowest during April and tended to decrease as water velocity increased, whereas their distribution in the inner section tended to be the opposite (Figure 8). Although migrating fish also tended to be distributed predominately in the outer section, there was no meaningful trend with time or water velocity.

Discussion

The test apparatus and protocol worked well and provided highly consistent data within the individual test series. The only problem with the apparatus occurred between the 25 and 26 April night and day series when eight of the test fish escaped from the flume into the center portion of the tank. The range and overlap in length of the hatchery and actively migrating groups of fish tested were not as large as desired. This resulted from relatively slow growth by the hatchery fish and collection of the migrating fish so far downstream at Bonneville Dam.

The swimming behavior exhibited by hatchery subyearling chinook salmon in this study was similar to that of yearling hatchery coho salmon even though the test protocols were dissimilar (Flagg and Smith 1981). Both studies documented a
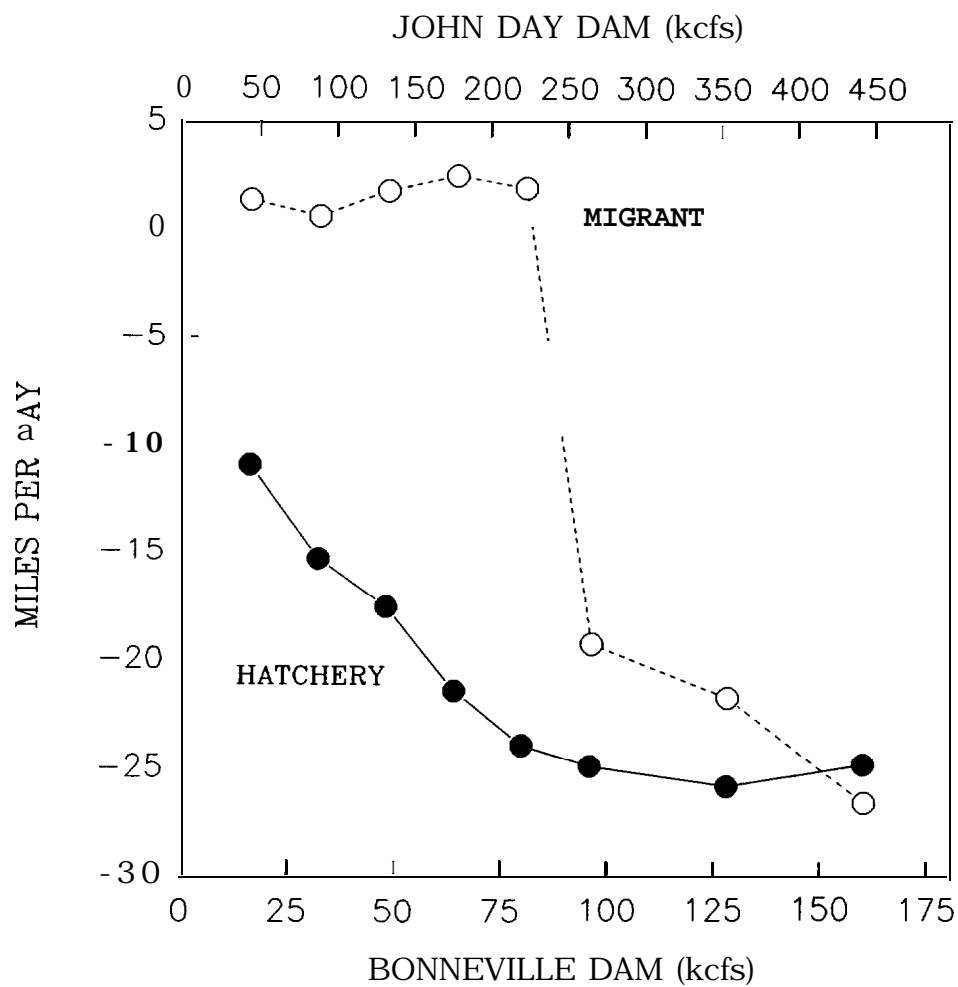
Figure 6.-Hypothetical miles traveled per June day in John Day and Bonneville pools at various discharges from the respective dams by subyearling chinook salmon from Little White Salmon NFH and migrating fish from Bonneville Dam.

MIGRANT

HATCHERY
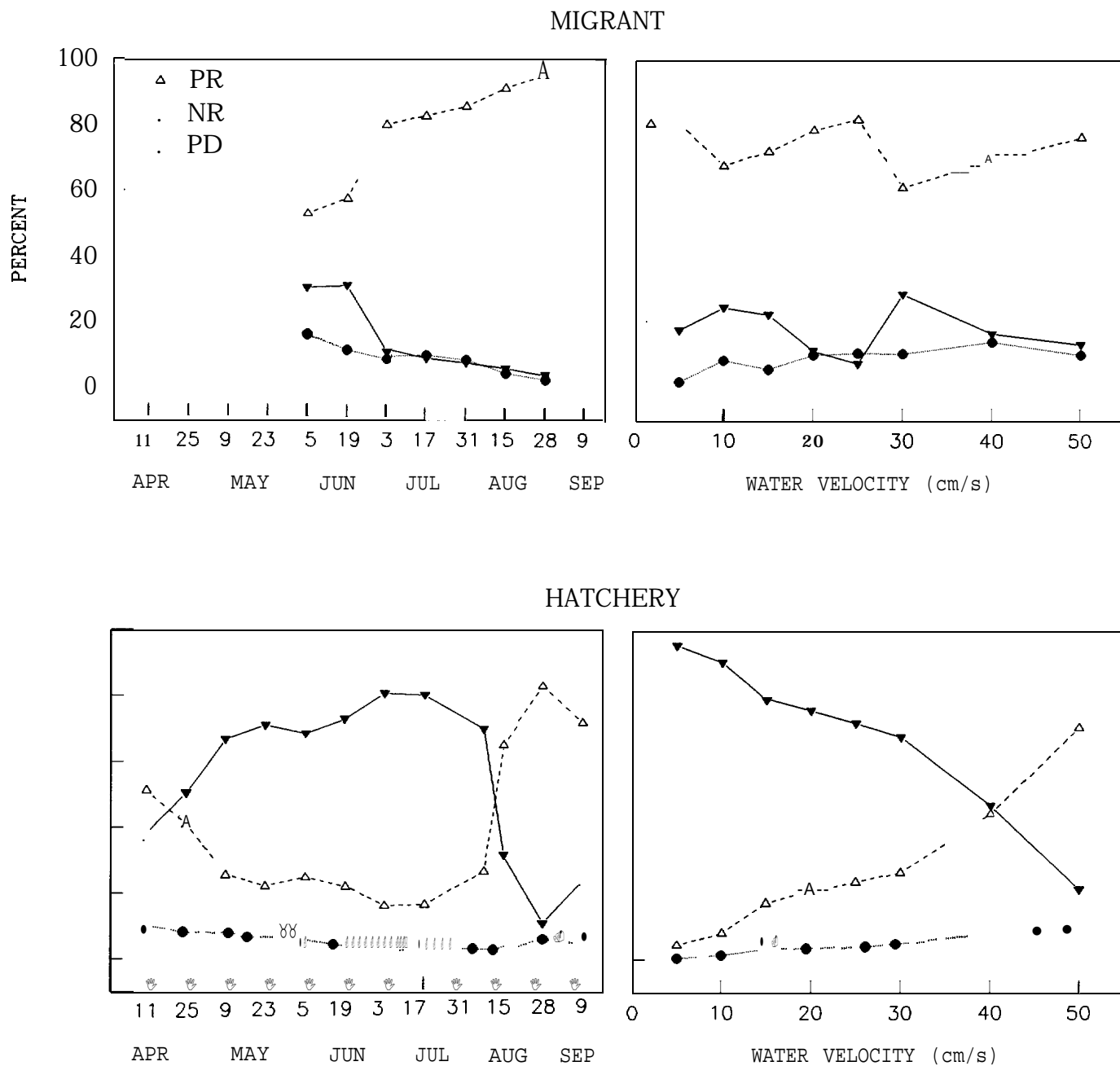
Figure 7.—Mean day-night percent rheotactic orientation of subyearling chinook salmon from Little White Salmon NFH and migrants from Bonneville Dam by date and water velocity tested. PR = positive rheotaxis, NR = negative rheotaxis, and PD = passive drift.

MIGRANT

HATCHERY
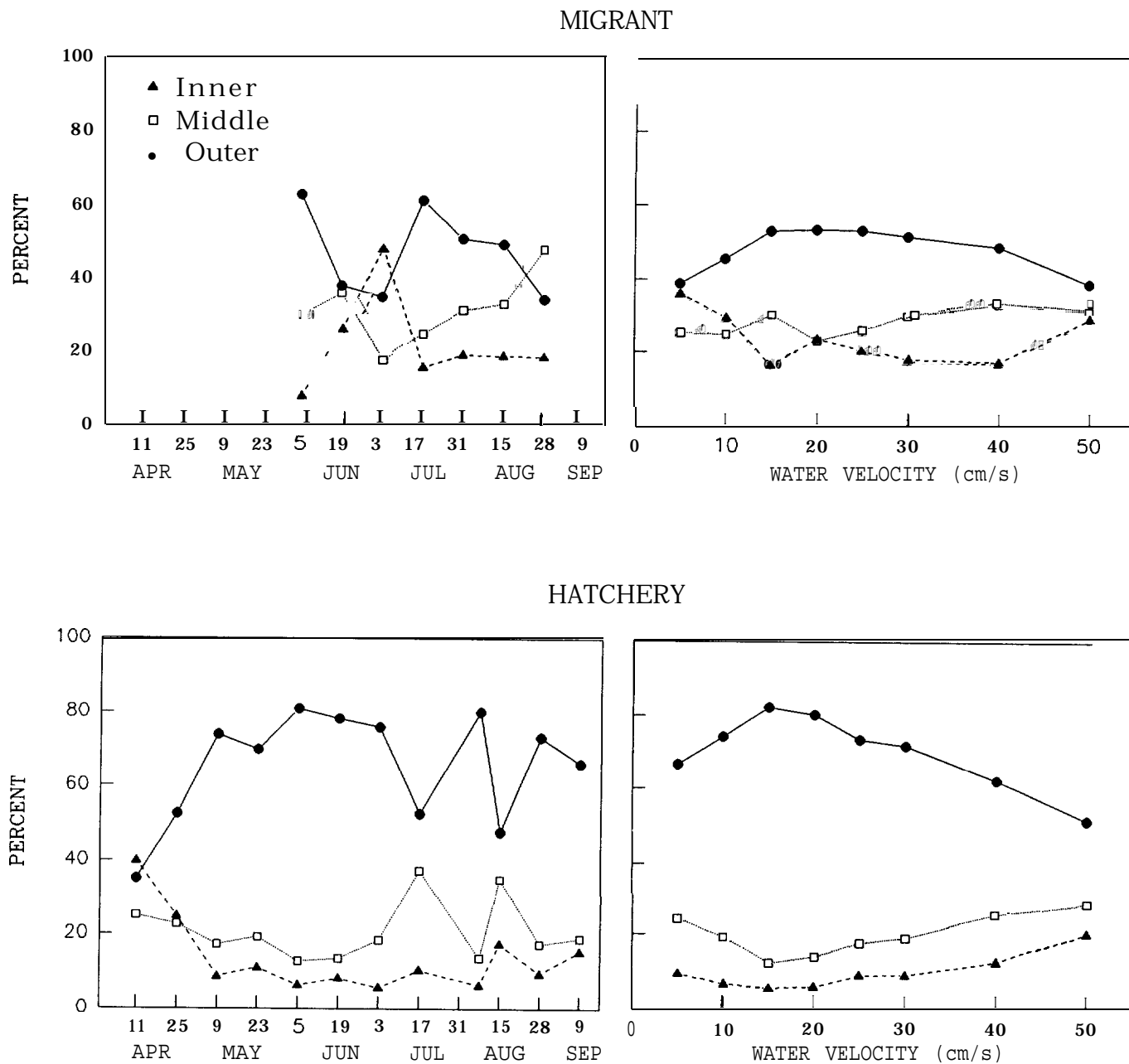
Figure 8. -Mean day-night percent distribution across the flume of subyearling chinook salmon from Little White Salmon NFH and migrants from Bonneville Dam by date and water velocity tested, 1991.

decrease in maximum swimming velocity from about eight to near zero bl/s as the fish smolted followed by a recovery to about four bl/s. However, the present study also documented unanticipated behavior patterns when the hatchery fish exhibited negative rheotaxis when subjected to water velocities less than about 40 cm/s during May, June, and July and exhibited less downstream movement at night than during the day.

The swimming behavior of hatchery fish differed from that of migrating fish. The migrating subyearling chinook salmon consistently exhibited positive rheotaxis except when water velocities exceeded about 30 cm/s during the two daytime trials conducted in June. This strong positive rheotaxis exhibited at low water velocities during the day would explain why subyearling chinook salmon have been documented to move upstream in John Day Reservoir (Miller and Sims 1984). In a 1981-83 study of the effects of flow in John Day Reservoir on the migration of subyearling chinook salmon, 54% of the marked fish were subsequently recovered upstream from where they had been captured and released (Giorgi et al. 1990). In the present study migrating fish exhibited the expected reduction in magnitude of positive rheotaxis from day to night whereas for hatchery fish the opposite was documented.

Subyearling chinook salmon from Little White Salmon NFH exhibited their minimum swimming velocity (i.e. maximum displacement) during July when they were about 7-8 cm long whereas the migrating fish exhibited their minimum swimming velocity during June when they were 9-10 cm long. During these periods the maximum swimming velocities of fish from both sources seldom exceeded 2.5 bl/s and were commonly 1-2 bl/s. The decrease in maximum swimming velocity shown by hatchery fish from April to July was gradual with no specific size or time threshold at which their swimming velocity declined abruptly. The level of gill ATPase activity in hatchery fish was significantly correlated with their mean swimming velocity but not with their maximum swimming velocity. The level of gill ATPase activity in migrating fish was not significantly correlated with their mean or maximum swimming velocity.

The change observed in June for migrating fish from positive to negative rheotaxis indicated a water velocity threshold of about 30 cm/s existed. The fact the same behavior was observed in groups of fish collected two weeks apart indicates the behavior was not due to random variation. As shown in Figures 3 and 6, a velocity threshold of about 30 cm/s would have no practical affect on the migration of subyearling chinook salmon in reservoirs such as Bonneville because summer flows normally provide higher water velocities. However, summer flows in John Day Reservoir are commonly less than the 225 kcfs required to produce water velocities of 30 cm/s. Assuming fish reacted in the reservoir in the same manner as they did in the laboratory,

this apparent water velocity threshold may affect the migration of subyearling chinook salmon in this reservoir.

In summary, hatchery and migrating subyearling chinook salmon displayed their greatest disposition to be displaced during June and July when they were 7-10 cm in length. During displacement, fish actively swam upstream at velocities less than that of the water velocity, usually at velocities just sufficient to maintain their equilibrium but no greater than 2.5 bl/s. Passive drift by fish was rarely observed. Hatchery fish tended to be displaced at greater rates during the day than during the night and tended to actively swim downstream from May through early August. Conversely, migrating fish tended to be displaced at greater rates during the night than during the day except at water velocities exceeding 30 cm/s in June when they actively swam downstream. Future studies should use subyearling chinook salmon collected from McNary and John Day reservoirs from May-August to increase the probability of testing fish which were naturally produced and exhibit as wide a range in size and physiological development as possible.

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CHAPTER THREE

Subyearling Chinook Salmon Marking at McNary Dam to

Estimate Adult Contribution

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Introduction

Research conducted at McNary Dam from 1981 to 1983 determined that subyearling chinook salmon *Oncorhynchus tshawytscha* which emigrated earlier in the summer exhibited greater adult contribution than did those emigrating later in the summer (Giorgi et al. 1990). No physical or biological factor could be isolated as a causal factor for this phenomenon even though a primary objective of the study was to examine the influence of flows on juvenile emigration and survival, which were about 10% to 40% above average during the study period. Giorgi et al. (1990) attributed this failure to an inability to recover sufficient numbers of marked fish at John Day Dam to estimate their travel time through John Day Reservoir and the interaction among flow, temperature, fish size, physiological development and origin of the fish.

This study task was initiated in an attempt to resolve the questions pertaining to the influence of summer flows below the Snake and Columbia river confluence on the emigration of subyearling chinook salmon and their contribution as adults. Primary objectives for this first year of the study were to determine if sufficient numbers of subyearling chinook salmon marked and released at McNary Dam could be recovered at John Day Dam to estimate their travel time and if the different groups marked at McNary Dam remained temporally discrete when emigrating from John Day Reservoir. A secondary objective was establishment of a data base on the size and physiological development of the fish for later analysis if the primary objectives were attained.

Methods

Juvenile chinook salmon were subsampled from the juvenile fish collection system at McNary Dam and marked to determine adult return rates. The dam is equipped with traveling screens to divert the juvenile fish from the turbine intakes into gatewells and to raceways. A subsample of the fish entering the collection facility was obtained by operation of a timed gate in the conduit moving fish to the holding raceways. Each subsample was collected by repeated sampling during a 24 h period starting at 0700 hours. The subsample rate ranged from about 5% to about 20%.

Subyearling chinook salmon were marked with coded wire tags (CWT) and branded with cold brands (Jefferts et al. 1963; Everest and Edmundson 1967). Fish were anesthetised with a preanesthetic of benzocaine (ethyl P-aminobenzoate) and an anesthetic of MS-222 (tricaine methanesulfonate) similar to that described by Matthews (1986). Juvenile fish were then sorted by species and marked with CWT and cold brands. Three segments of the migration were

marked: early, middle, and late. For each segment of the migration, three CWT codes were used resulting in a total of 9 CWT codes released in 1991. Each day of the marking, fish were marked with cold brands with unique combination of a character, location, and rotation to identify the fish marked on that day for subsequent determination of migration time from McNary Dam to John Day Dam. Marked fish were released into the fish bypass system at McNary Dam between 2200 and 2300 hours on the day of marking. At John Day Dam juvenile salmon were collected using an air-lift pump (Brege et al. 1990) and the brands on recaptured fish were recorded.

The marking program included measures to ensure the quality of subyearling chinook salmon released at McNary Dam. Fish that were previously branded or adipose fin clipped and CWT tagged, descaled, or had injuries likely to result in mortality were not marked (Wagner 1992). Fish with fork lengths less than 55 mm were also not marked. One hundred fish per day were held for 48 h to measure delayed mortality and coded wire tag loss. The fish held for delayed mortality were transported downstream by barge or truck to prevent confounding of migration time estimates to John Day Dam.

Travel time of branded replications of fish was estimated by the method used by the Fish Passage Center i.e., the difference between the median date of release at McNary Dam and the date nearest the median date of recovery based on the passage indices at John Day or Bonneville dams. However, we only estimated travel time to the nearest day and did not interpolate to the nearest tenth of a day. Flow and temperature during the travel time was estimated by averaging the discharge and temperature at John Day Dam from the day after fish release at McNary Dam through the median day of recovery at John Day Dam.

Results and Discussion

Columbia River flows at McNary Dam decreased from about 300 kcfs in early June to about 125 kcfs in late August and temperatures increased from about 12°C to 22°C during the same period (Figure 1). Flows during June and July were about 70% of the 50 year average; August flows were about 105% of the 50 year average.

The mean date of subyearling chinook salmon emigration past McNary Dam in 1991 was 6 July, or three days later than the 1984-90 mean, but the 10% and 90% passage dates were about 10 days later than the 1984-90 mean (Figure 1; Fish Passage Center 1992). The median date of passage at McNary Dam of branded or PIT tagged wild subyearling chinook salmon captured and released from 5 to 13 June in the Hanford Reach was 12 and 13 July (Wagner 1992). The median dates of passage at McNary Dam of branded subyearling fall chinook salmon released from Priest Rapids State Fish

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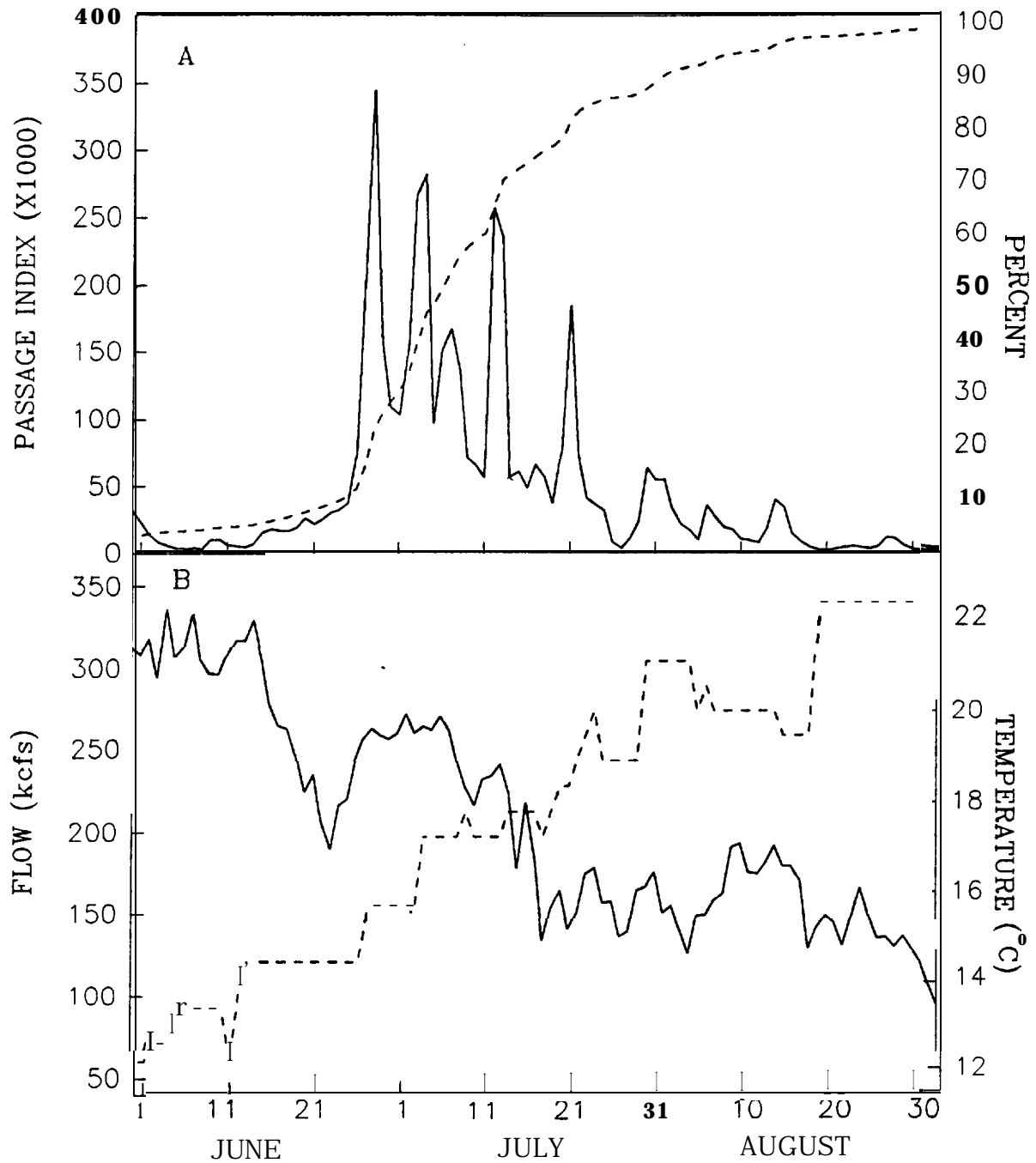
Figure 1.—Daily (solid line) and cummulative (dashed line) passage index (X1000) of subyearling chinook salmon (A) and daily flow (solid line) and temperature (dashed line; B) at McNary Dam, 1991.

Hatchery (SFH) between 14 to 25 June ranged from 1 to 11 July. The median date of passage for branded subyearling summer chinook salmon released on 24 June from Wells SFH was 24 July (Fish Passage Center 1992).

A total of 105,088 subyearling chinook salmon collected at McNary Dam were freeze branded, coded wire tagged, and released in the tailrace (Table 1). An additional 3,000 marked fish were transported after being retained for 48 h to estimate delayed mortality and CWT loss. The group of 35,591 early emigrants were marked with 11 unique brands from 20 to 30 June which corresponded to when the cummulative passage index increased from 12% to 29%: delayed mortality and tag loss was 0.4% (Appendix 5). The middle group of 36,006 emigrants were marked with 8 unique brands from 9 to 16 July which corresponded to when the passage index increased from 58% to 74%; delayed mortality and tag loss was 0.4%. The late group of 36,091 emigrants were marked with 11 unique brands from 24 July to 3 August which corresponded to when the passage index increased from 86% to 94%: no tag loss was observed but delayed mortality was 2.1% for this group.

Recaptures at McNary Dam of wild and hatchery produced subyearling chinook salmon, that were marked and released upstream, indicated the early group of marked emigrants were composed almost exclusively of Priest Rapids Hatchery fish and the middle and the late groups included both hatchery and wild fish. Efforts to identify the origin of the marked fish by electrophoresis were not initiated since this method can not discriminate the stocks of concern i.e., wild and hatchery produced summer and fall chinook salmon (Schreck et al. 1986).

Fish in the 26 July replication were applied the same brand that was previously used on 28 June. From 3 to 25 July twelve fish were recaptured at John Day Dam that exhibited the brand that must have been applied on 28 June, but three fish were recaptured from 6 to 8 August which could have been from either replication. Therefore, the 26 July replication and the three recaptured in August were excluded from all further analysis.

The number of subyearling chinook salmon recaptured at John Day Dam ranged from 29 to 80 fish for the nine coded-wire tag replications and from 102 to 226 for the three groups (Figure 2 and Table 2). Estimated travel times were 6, 20, and 11 days for the early, middle, and late groups, respectively. The estimated migration rates from McNary Dam to John Day Dam were 20, 6, and 11 km/d for early, middle, and late groups, respectively. The Kruskal-Wallis test indicated the time of emigration for the three groups past John Day Dam was significantly different ($X^2 =$ 321.6; $P < 0.001$) and Tukeys test ($P < 0.05$) indicated all three groups were significantly different from each other.

Table 1. The date, coded-wire tag code, and number of subyearling chinook salmon released in the tailrace of McNary Dam and the number of fish retained for 48 hours with their tag loss and mortality prior to transportation, 1991.

Date	CWT Code	Marked	Marked & Held	Mortality	Tag Loss	Percent Loss
June 20-25	27/11	11,218	650	2	0	0.3
June 26-27	27/10	12,000	200	0	1	0.5
June 29-30	27/9	11,623	300	2	0	0.7
Sub-Total		34,841	1,150	4	1	0.4
July 9-11	27/8	11,702	300	0	0	0
July 12-13	27/7	11,804	200	1	1	1.0
July 14-16	27/6	11,700	300	1	0	0.3
Sub-Total		35,206	800	2	1	0.4
July 24-29	27/5	11,489	550	17	0	3.1
July 30-31	26/63	11,824	200	3	0	1.5
Aug 1-3	26/62	11,728	300	2	0	0.7
Sub-Total		35,041	1,050	22	0	2.1
Total		105,088	3,000	28	2	1.0

Table 2. Median dates and number of subyearling chinook salmon released at McNary Dam and the number recovered, expanded index, and percent detected at John Day and Bonneville dams, 1991.

	MCNARY DAM RELEASE		RECOVERY AT JOHN DAY DAM				RECOVERY AT BONNEVILLE DAM			
CWT Code	MED. DATE	NUM BER	MED. DATE	NUM BER	INDEX	% DETECT	MED. DATE	NUM BER	INDEX	% DETECT
27/11	6-24	11,218	7-30	39	529	4.7	7-04	87	225	2.0
27/10	6-26	12,000	7-03	29	390	3.3	7-04	208	526	4.4
27/9	6-29	11,623	7-05	34	465	4.0	7-07	174	421	3.6
EARLY	6-27	34,841	7-03	102	1,384	4.0	7-05	469	1,172	3.4
27/8	7-11	11,702	7-23	77	871	7.4	7-25	117	151	1.3
27/7	7-12	11,804	7-27	69	790	6.7	7-27	68	91	0.8
27/6	7-15	11,700	8-05	80	864	7.4	8-06	45	61	0.5
MIDDLE	7-12	35,206	8-01	226	2,525	7.2	7-26	230	303	0.9
27/5	7-25	10,551	8-07	63	664	6.3	8-09	71	95	0.9
26/63	7-30	11,824	8-10	58	630	5.3	8-11	109	148	1.3
26/62	8-02	11,728	8-12	58	636	5.4	8-13	71	108	0.9
LATE	7-30	34,103	8-10	179	1,930	5.7	8-12	251	351	1.0
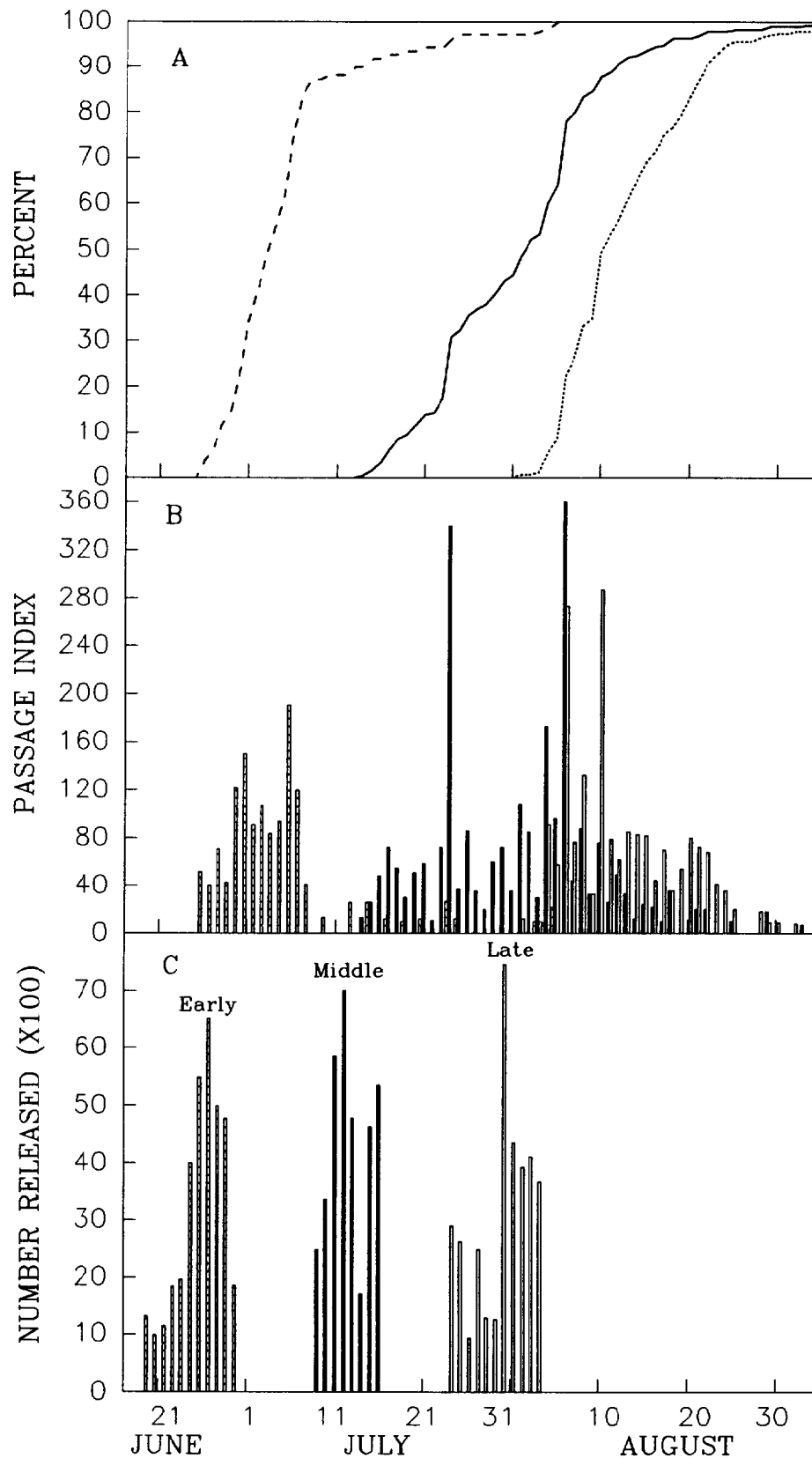
Figure 2.–Cummulative percent frequency distribution (A) and passage index (B) of early, middle, and late emigrating groups of subyearling chinook salmon recovered at John Day Dam and the number marked and released (C) at McNary Dam, 1991.

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The number of fish recaptured at Bonneville Dam ranged from 45 to 208 for the nine coded-wire replications and 230 to 469 for the three groups (Table 2). The median dates of recapture for the replications at John Day and Bonneville dams indicated the fish traveled rapidly through the Dalles and Bonneville reservoirs compared to travel time through John Day reservoir. The Kruskal-Wallis test indicated the time of emigration for the three groups past Bonneville Dam was significantly different (X^2 = 777.7: P < 0.001) and Tukey's test (P < 0.05) indicated all three groups were significantly different from each other.

The travel time of subyearling chinook salmon through John Day Reservoir was significantly correlated (P < 0.05) with flows (r = -0.754) and gill ATPase activity (r = 0.751) but not with date of release, temperature, or their length at release (Table 3). We believe the negative sign of the correlation between travel time and ATPase was most likely a spurious relation as a result of only two levels of flows during the observations. The flows were clustered with two points at about 260 kcfs and six points near 165 kcfs. The first three coded-wire tag replications were combined into two replications to increase the number of recoveries at John Day Dam.

Summary and Recommendations

1. The desired number of 108,000 subyearling chinook salmon emigrating during the early, middle, and late segments of the migration were successfully marked and released in nine replications of 12,000 fish at McNary Dam. Delayed mortality and tag loss (1.0%) was low.

2. Adequate numbers of branded fish were recaptured at John Day and Bonneville dams to estimate the three groups of fish maintained their integrity and emigrated separately in relation to when they were released.

3. Travel time of subyearling chinook salmon through John Day Reservoir was not significantly correlated with date of release, temperature, or fish size. A negative correlation between travel time of subyearling chinook salmon and flow and a positive correlation between travel time and ATPase activity suggested the effects of flow overwhelmed the effects of ATPase activity in this small data set.

4. Additional sampling equipment and recording recovery to the nearest hour at John Day Dam in 1992 will provide more accurate estimates of travel time in future years.

Table 3. Correlation of subyearling chinook salmon travel time from McNary Dam to John Day Dam with the median date of release, flow, temperature, ATPase activity, and fork length (FL) of the branded groups, 1991.

DATES	MEDIAN DATE	TRAVEL TIME(d)	FLOW (kcfs)	TEMP (c)	ATPase Activity	FL (cm)
Jun 20-26	25-Jun	5	256	15	16.2	10.0
Jun 27-30	28-Jun	7	261	16	14.6	10.1
Jul 09-11	11-Jul	12	178	18	30.5	10.1
Jul 12-13	12-Jul	15	171	18	29.7	9.9
Jul 14-16	16-Jul	21	157	19	29.7	9.9
Jul 24-29	25-Jul	13	157	19	28.7	10.6
Jul 30-31	30-Jul	11	163	20	28.0	10.9
Aug 01-03	02-Aug	10	167	21	28.0	10.8
r	0.383		-0.754	0.491	0.751	0.213

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CHAPTER FOUR

Evaluation of PIT Tagging of Subyearling

Chinook Salmon

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Introduction

Subyearling chinook salmon *Oncorhynchus tshawytscha* naturally produced in the Hells Canyon reach of the Snake River were tagged with passive integrated transponders (PIT) and recaptured at Lower Granite Dam to record time of emigration (Connor et al. 1992 in this report). Since the goal of this tagging was to better understand factors affecting their emigration, it was important to determine what effects tagging would have on subyearling chinook salmon behavior and survival. If PIT tagging significantly altered behavior, especially migratory behavior, then conclusions about their outmigration drawn from PIT tag recapture data could be erroneous. Furthermore, survival of tagged fish was a concern because the Snake River fall chinook salmon stock had declined to such low numbers it was being considered for listing under the Endangered Species Act. Tagging fish from this threatened population would be unacceptable if it caused high mortality.

Connor et al. (1992 in this report) anticipated that subyearling chinook salmon ranging from 55 mm to 70 mm would be readily captured by seine in nearshore habitats downstream from spawning areas in the Hells Canyon reach and conversely that larger fish would be widely dispersed in deeper habitats requiring large traps or weirs for capture. Therefore, if adequate numbers were to be tagged it would be necessary to implant tags in fish as small as 55 mm to 65 mm fork length.

During the development of PIT tags for use in juvenile salmonids considerable information was collected on the behavior and survival of fish after tagging (Prentice et al. 1990a). They measured growth, survival, and PIT-tag retention for subyearling chinook salmon with mean fork lengths ranging from 66 mm to 100 mm: survival ranged from 95 to 100% for about 135 d. Less than 12% mortality 45 d after tagging was reported for juvenile steelhead *O. mykiss* with mean fork lengths 80 mm to 129 mm (Prentice et al. 1986). Although the results of Prentice et al. (1990a) did not demonstrate a relationship between fish size and tagging mortality rate or tag retention rate, the fish we would be tagging were smaller than those other investigators had tested. Because the PIT tags were 12 mm long we anticipated there would be a minimum fish size below which tagging would be lethal and that limit had not been determined.

This study was designed to quantify the effects of PIT tagging procedures on the survival of 55 mm to 70 mm subyearling chinook salmon. We also wanted to determine whether tagging significantly changed salmon behavior which could bias our interpretation of their emigration timing. In addition to mortality tests, we used swim performance and predation

vulnerability as quantifiable indicators of the effects of
tagging. Swim performance and predation vulnerability were used
by Barns (1967) to compare the viability of artificially produced
sockeye salmon *O. nerka* fry to naturally produced fry. We
evaluated swimming stamina as an indication of physical condition
of the fish. Predation vulnerability tests were conducted to
evaluate the effects tagging had on complex behavior; in this
case predator avoidance.

Methods

All subyearling fall chinook salmon used in these
experiments were of the upriver bright stock obtained from Little
White Salmon National Fish Hatchery. The upriver bright stock of
fall chinook salmon was selected as a surrogate experimental
animal for the Snake River stock because they are closely related
and were readily available.

Ten to 15 experimental fish were netted from a holding tank
and placed in a bucket of water containing 26 mg/L tricaine
methanesulfonate (MS-222) anesthetic in preparation for tagging.
Prior to tagging fish were removed from the bucket and weighed
and measured. Fish were then held for tag insertion in a slit on
a sponge. PIT tags used in these experiments were approximately
12 mm in length and 2 mm in diameter. Each PIT tag was inserted
into a 12 gauge hypodermic needle prior to tagging. The needle
was inserted into the fish so that the **bevelled** tip completely
penetrated beneath the surface of the skin at a point on the
midline of the ventral surface posterior to the pectoral fins.
The tag was pushed out of the needle so it was positioned just
beneath the skin anterior of the wound. Then the needle was
backed out of the wound and the wound was swabbed with
disinfectant. The fish was placed in aerated water to revive it
from the anesthetic. These operations constituted the act of PIT
tagging the fish and use of the word tagging in this paper refers
to this process. Each fish required approximately 1 minute 30
seconds to tag after removal from the anesthetic; including
weighing and measuring. In each type of test described below PIT
tagged fish are referred to as treatment fish and fish without
tags are controls.

Swimmina Stamina

Swimming stamina of subyearling chinook salmon was estimated
using a Blazka respirometer (Blazka et al. 1960). Swimming
stamina was determined after fish were allowed post-tagging
recovery periods of 0.5, 4, 24, 48, or 96 h. After recovery, six
fish were selected randomly from control and treatment fish
holding tanks. Fish from each group were placed in two separate
compartments of a swim chamber. To keep track of individual

fish, each was identified by unique natural markings such as parr marks.

The swim chamber was calibrated prior to testing by placing a Marsh-McBirney water velocity meter in the swim chamber to measure water velocity. Water flow was generated by an impeller at the rear end of the swim chamber which was turned by a variable speed electric motor. Impeller turning speed was measured by a tachometer. A plot was generated of flow velocities measured by the flow meter in the swim chamber and the revolutions per second of the impeller. The tachometer was then used during the course of the swim tests to indicate water velocity in the swim chamber.

An electrified grid at the downstream end of the swim chamber was used to stimulate fish to swim to exhaustion. Black plastic was wrapped around the central portion of the swim chamber and the downstream end of the chamber was illuminated with a 100 watt light to discourage fish from seeking refuge from velocity in front of the electrified grid.

Fish were given 0.5 h to acclimate in the swim chamber before testing began. Those fish held for the 0.5 h recovery period were placed in the swim chamber immediately after tagging and allowed to acclimate. During the first replicate of swim performance tests water temperatures at the end of the swim tests were 13°C to 14°C due to low volume of water circulation. Water temperature during the second replicate of swim tests was held between 10.4°C and 11.6°C by circulating fresh water through the chamber. Water velocity for each swim test began at 1.5 body lengths per second (bl/s) and was increased 0.5 bl/s every 15 min. One body length was defined as 60 mm although fish ranged in length from 49 mm to 63 mm. Tests were continued until all fish were fatigued. A fish was considered fatigued when it lodged against the grid.

Time of fatigue, U-critical, was calculated for each fish using the following formula from Beamish (1978):
U-critical $= U_i + (t_i/t_{ii} * U_{ii})$; where, U_i = highest velocity increment during which fish was not fatigued, U_{ii} = velocity increment (0.5 bl/s), t_i = time (min) fish swam during final increment, and t_{ii} = time period of each increment (15 min).

A general linear model analysis of variance (ANOVA) was used to analyze the importance tagging and recovery period had on swim performance. The general linear model was used because of the unbalanced design of the experiment (SAS 1988). Three other variables, chamber position, experimental replicate, and fork length, were included in the analysis to determine what effects each had upon the swim test results. Mean U-criticals for treatment and control groups in each trial were also compared

using the Tukey method for t-tests to further analyze the importance of recovery period for each trial.

Predation Vulnerability

The primary measure of relative performance in the predation vulnerability experiment was the number of subyearling chinook salmon treatment and control fish that were consumed by smal lmouth bass *Micropterus dolomieui*. Tanks in which the experiments were conducted measured 1.2 m in diameter. Four segments of 20 cm diameter polyvinyl chloride pipe were placed in each tank to provide structural diversity and cover. Treatment and control groups were simultaneously introduced into a tank holding four smallmouth bass and exposed to predation risk for 24 h. Water temperature in the tanks was $10^{\circ}C$. Groups of treatment and control fish were allowed either 0.5 h or 96 h recovery time prior to predation exposure. Control fish were held under the same conditions as treatment fish before introduction into tanks where experiments were conducted. Subyearling chinook salmon used in predation experiments ranged from 48 mm to 73 mm fork length with a 59 mm mean fork length. Smallmouth bass chosen randomly from a holding tank were given at least 24 h to acclimate to the tanks prior to introducing subyearling chinook salmon. Smallmouth bass were not fed during the acclimation period. Smallmouth bass length ranged from 199 mm to 268 mm fork length; weight ranged from 111 g to 242 g. At the beginning of each predation experiment 32 treatment and 32 control fish were simultaneously introduced into the tank. After 24 h all survivors were removed, weighed, measured, and identified as treatment or control fish by examining their ventral surface for insertion scar and scanning with a PIT tag detector (Prentice et al. 1990b). Predators were also weighed and measured at the end of each 24 h test. Three replicates of the predation experiment were conducted for 0.5 h and 96 h recovery groups in each of the trials that started 10 May and 17 May.

Chi-square goodness of fit tests were used to compare the number of treatment and control fish eaten to the expected number eaten in each group within each tank. The null hypothesis was that prey selection by smallmouth bass did not vary from random feeding. Alternatively, the hypothesis was stated as an expression of prey vulnerability; treatment or control fish were not consumed in greater numbers than their relative proportion in the tank: 0.5 h and 96 h recovery tests were analyzed separately. Chi-square heterogeneity tests were applied to data for all tanks of a recovery group to test whether the proportion of treatment and control fish eaten varied among tanks. Where heterogeneity was not significant, data from all tanks of that recovery period were pooled and an overall chi-square test used. For tanks in which there was no significant difference in the

number of treatment and control fish eaten statistical power was calculated using Design-Power program (Bavry 1984). Size selectivity of treatment fish by predators was tested using a Kolmogorov-Smirnov test; the cumulative length frequency distribution of surviving treatment fish was compared to that of treatment fish initially introduced into the tanks.

We also conducted tests to compare the vulnerability of sham-tagged fish to control fish. Fish were sham tagged by inserting the tag injection needle into their abdomen without inserting a PIT tag. Equal groups of 32 sham-tagged fish and 32 controls were subject to predation as described for the other predation tests. Results were analyzed using chi-square tests to determine if predators were selectively depredating sham or control fish as was done for the PIT tag tests.

Tag Retention and Delayed Mortality

Treatment and control groups of subyearling chinook salmon were held in separate 0.5 m diameter tanks for 96 h after tagging to assess mortality. Water temperature in the tanks was $10^{o}C$. Two groups of 40 fish were anesthetized and tagged and then held in separate tanks. Two groups of 40 control fish were also held in separate tanks identical to those holding the tagged fish. Fish were not fed during the 96 h they were held. In the first trial, the mean fork length of treatment fish was 57 mm compared to 55 mm for the control fish. During the second trial, mean fork length of treatment fish was 63 mm and the mean fork length of control fish was 60 mm. Tanks were checked 24, 48, 72, and 96 h after PIT tagging. All dead fish were removed, counted, weighed, and measured. Fish from the treatment groups were examined for tags. At the end of 96 h all fish were removed from the tanks, weighed, measured, and treatment fish checked for tag retention.

Following the 1991 trials which we reported here, we conducted a series of trials in which subyearling chinook salmon of the upriver bright stock were tagged and held for 90 d. The tagging protocol was the same as used for the experiments described here except that the anesthetic used in the 1992 tests was buffered with 0.1 g salt and 3.5 g baking soda per gallon of water. One milliliter of polyproaqua (synthetic slime) was also added to the solution. Groups of 100 treatment fish and 100 control fish were held in each of 3 rearing tanks (N = 600). The mean fork length of fish were 57, 65, and 72 mm for the treatment fish and 56, 65, and 72 mm for the control fish.

Swimming Stamina

The presence or absence of PIT tags in subyearling chinook salmon was significant in explaining the variability in swimming stamina as measured by U-critical swimming speed (ANOVA; $P < 0.05$). An interaction variable (tagging by recovery period) was also significant in the ANOVA, indicating that swim performances of treatment and control fish were affected differently depending on recovery period. Swim chamber position, experimental trial, and fork length were not significant variables in the ANOVA ($P > 0.05$).

Fish tested after 0.5 h recovery period had significantly lower swimming stamina than those allowed 4 or more hours recovery time when compared using Tukey's test of means (Table 1 and 2). In general, U-criticals of treatment fish were lower than controls when allowed 0.5 h recovery, but comparable with controls when tagged fish were allowed four or more hours recovery (Figure 1).

Predation Vulnerability

During the 0.5 h recovery tests smallmouth bass consumed a larger proportion of treatment fish than control fish in all tanks (Figure 2). The heterogeneity chi-square test comparing the proportion of treatment and control fish eaten in all tanks was not significant for the 0.5 h recovery tests. Therefore, data was pooled from all six tanks of the 0.5 h recovery replicates and the pooled chi-square calculated (Sokal and Rohlf 1981). The pooled chi-square was significant indicating that a greater proportion of treatment fish were eaten than would be expected if predation was random. Additionally, individual chi-square tests for three of the six 0.5 h recovery tanks showed a significant difference in the number of treatment and control fish that were eaten (Table 3).

When the subyearling chinook salmon were allowed 96 h to recover prior to the predation test there was no significant trend in feeding selectivity by smallmouth bass for either treatment or control fish (Figure 2). The chi-square test for heterogeneity was significant so that pooling the data for all six 96 h predation tanks was not appropriate. The number of treatment and control fish eaten was not significantly different in any tank of either trial one or trial two (Table 4).

Results of the sham-tag tests also showed no significant trend in selectivity by smallmouth bass (Figure 3). For the 0.5 h recovery period, chi-square values comparing treatment and control fish showed no significant difference in any trial. In tank four, 16 treatment fish and 8 control fish were eaten and

Table 1. **Tukey's** studentized range (HSD) test of mean **U-criticals** for each recovery period for PIT-tagged and control groups. The 95% confidence limits were calculated with alpha = 0.05, df = 158, MSE = 2.890148, and a resulting critical value of Studentized Range = 3.903. Comparisons significant at the **P** < 0.05 level are indicated by asterik **(*)**.

Recovery comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
0.5 − 96	-2.921	-1.964	-1.006	*
0.5 − 24	-3.091	-1.918	-0.746	*
0.5 − 4	-2.700	-1.527	-0.354	*
0.5 − 48	-2.470	-1.297	-0.125	*
4 − 96	-1.610	-0.437	0.736	
4 − 24	-1.746	-0.391	0.963	
4 − 48	-1.125	0.230	1.584	
4 − 0.5	0.354	1.527	2.700	*
24 − 96	-1.218	-0.045	1.127	
24 − 4	-0.963	0.391	1.746	
24 − 48	-0.733	0.621	1.975	
24 − 0.5	0.746	1.918	3.091	*
48 − 96	-1.839	-0.666	0.506	
48 − 24	-1.975	-0.621	0.733	
48 − 4	-1.584	−0.230	1.125	
48 − 0.5	0.125	1.297	2.470	*
96 − 24	-1.127	0.045	1.218	
96 − 4	-0.736	0.437	1.610	
96 − 48	-0.506	0.666	1.839	
96 − 0.5	1.006	1.964	2.921	*

Table 2. Mean U-critical, lengths and standard deviations are listed by time of recovery after tagging for each group of six treatment and six control fish swum simultaneously in a divided respirometer.

Recovery Period	PIT Tag		Control	
	Mean FL (SD)	Mean Ucrit. (SD)	Mean FL (SD)	Mean Ucrit. (SD)
Trial 1				
0.5 hours	58 (1.00)	3.09 (1.87)	58 (1.26)	5.99 (0.82)
0.5 hours	58 (1.11)	3.76 (2.38)	58 (1.34)	6.69 (1.13)
24 hours	57 (1.34)	8.60 (2.26)	56 (2.69)	7.87 (2.09)
24 hours	56 (2.05)	6.60 (1.73)	58 (2.67)	7.49 (0.92)
96 hours	58 (1.41)	7.70 (1.79)	56 (1.80)	7.92 (1.05)
96 hours	60 (0.50)	8.26 (1.37)	56 (1.68)	8.10 (1.09)
Trial 2				
0.5 hours	58 (1.77)	6.47 (2.00)	60 (1.57)	7.16 (1.02)
0.5 hours	59 (1.89)	5.00 (2.89)	57 (1.41)	7.36 (1.05)
4 hours	60 (1.60)	7.07 (0.88)	55 (2.13)	7.11 (0.64)
4 hours	58 (2.99)	7.16 (2.54)	60 (2.03)	7.41 (1.42)
48 hours	56 (1.60)	6.88 (1.45)	56 (4.47)	6.60 (1.43)
48 hours	57 (3.44)	7.14 (1.70)	57 (1.49)	7.46 (0.83)
96 hours	56 (0.96)	7.50 (0.54)	53 (3.42)	6.89 (0.87)
96 hours	58 (1.80)	7.60 (0.35)	56 (3.67)	7.53.(0.57)
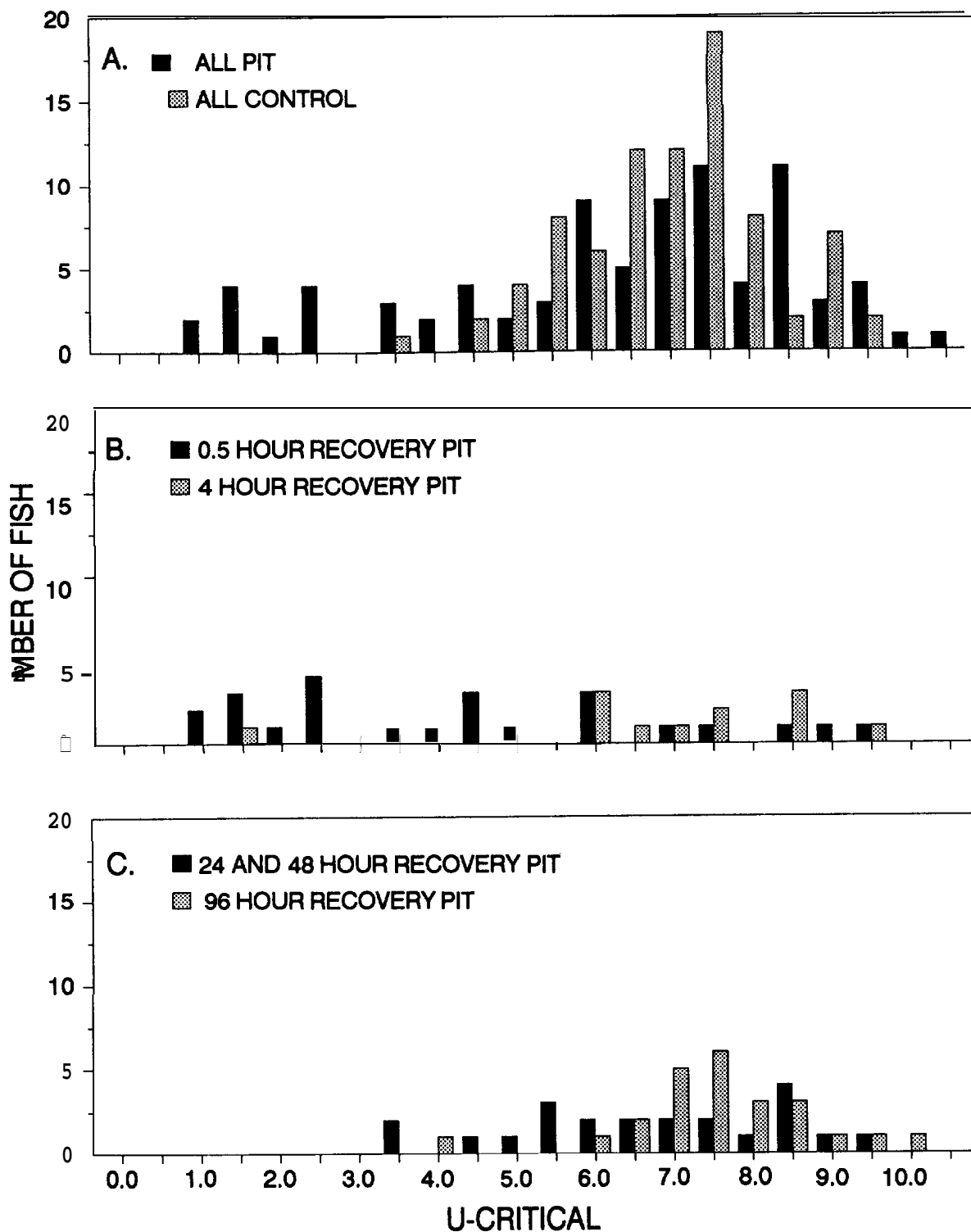
Figure 1. Frequency histograms of U-critical values for all fish tested. A. All PIT-tagged and all control fish. B. PIT-tagged fish with 0.5 h and 4 h recovery periods. C. PIT-tagged fish with 24 h, 48 h, and 96 h recovery periods.

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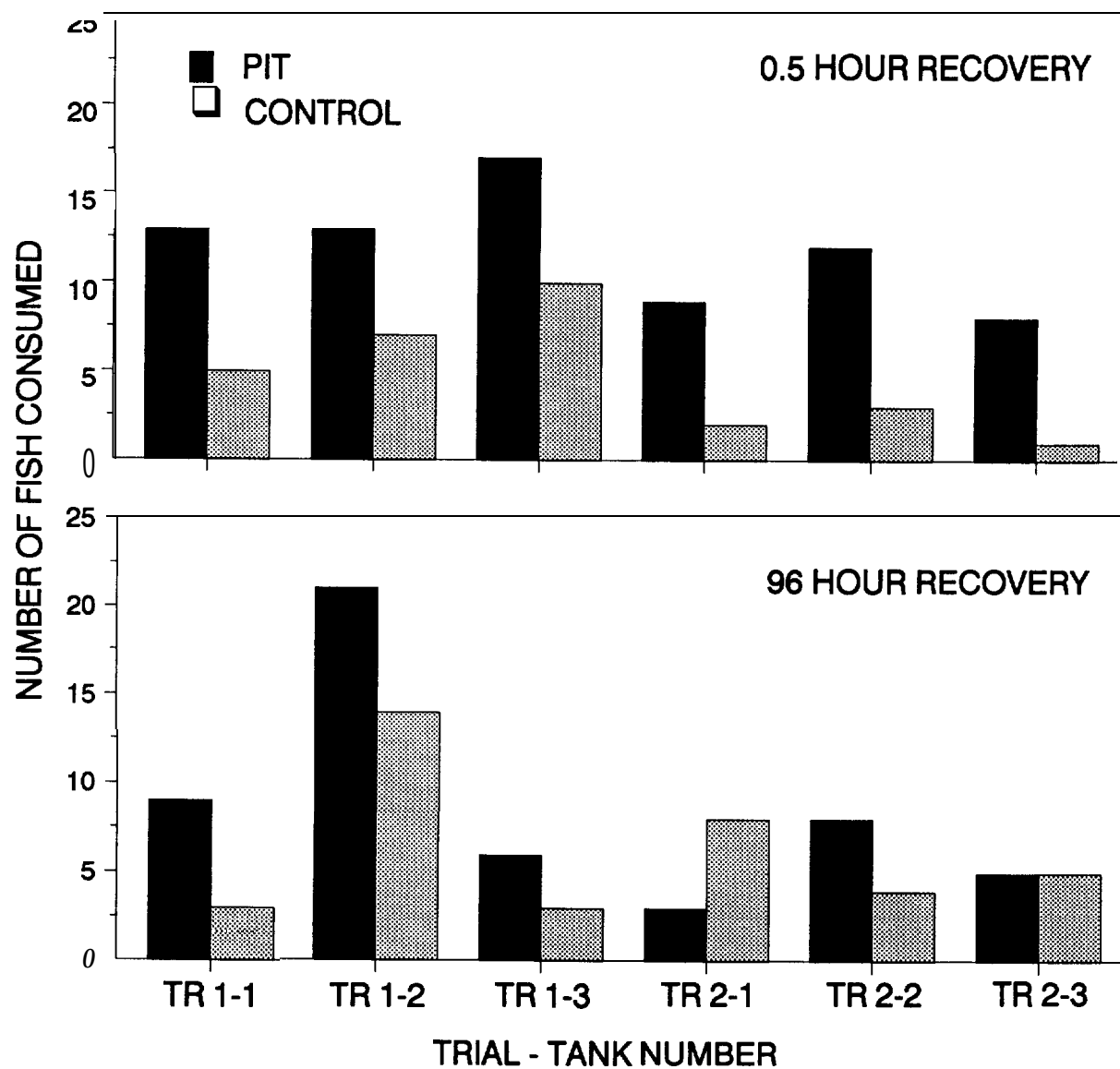
Figure 2. Total number of subyearling chinook salmon eaten in predation vulnerability trials. Trials begun on May 10 and May 17 are shown separately as are individual tanks (1, 2, and 3) in which tests were conducted. The two recovery periods, 0.5 h and 96 h, are included for comparison.

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Table 3. Results of predation risk experiment in which PIT tagged subyearling chinook salmon allowed 0.5 h recovery and controls were exposed to 24 h predation risk by smallmouth bass.

Tag	Trial-tank number	Number eaten	Expected number eaten	Chi-square	P-value	Power
PIT		13				
	1-1		9.0	3.556	0.056	0.47
Control		5				
PIT		13				
	1-2		10.0	1.800	0.176	0.27
Control		7				
PIT		17				
	1-3		13.5	1.836	0.174	0.27
Control		10				
PIT		9				
	2-1		5.5	4.455	0.033	
Control		2				
PIT		12				
	2-2		7.5	5.400	0.019	
Control		3				
PIT		8				
	2-3		4.5	5.440	0.019	
Control		1				
PIT		72				
	Pooled		50.0	19.360	0.00002	
Control		28				
Total				22.469	0.0005	

Table 4. Results of predation risk experiment in which PIT tagged subyearling chinook salmon allowed 96 h recovery and controls were exposed to 24 h predation risk by smallmouth bass.

Tag	Trial-tank number	Number eaten	Expected number eaten	Chi-square	P-value	Power
PIT		9				
	1-1		6.0	3.000	0.080	0.41
Control		3				
PIT		21				
	1-2		17.5	1.400	0.235	0.22
Control		14				
PIT		6				
	1-3		4.5	1.000	0.681	0.17
Control		3				
PIT		3				
	2-1		5.5	2.273	0.127	0.33
Control		8				
PIT		8				
	2-2		6.0	1.333	0.247	0.21
Control		4				
PIT		5				
	2-3		5.0	0.000	1.000	0.05
Control		5				
PIT		52				
	Pooled		44.5	2.528	0.107	0.36
Control		37				
Total				9.006	0.1087	
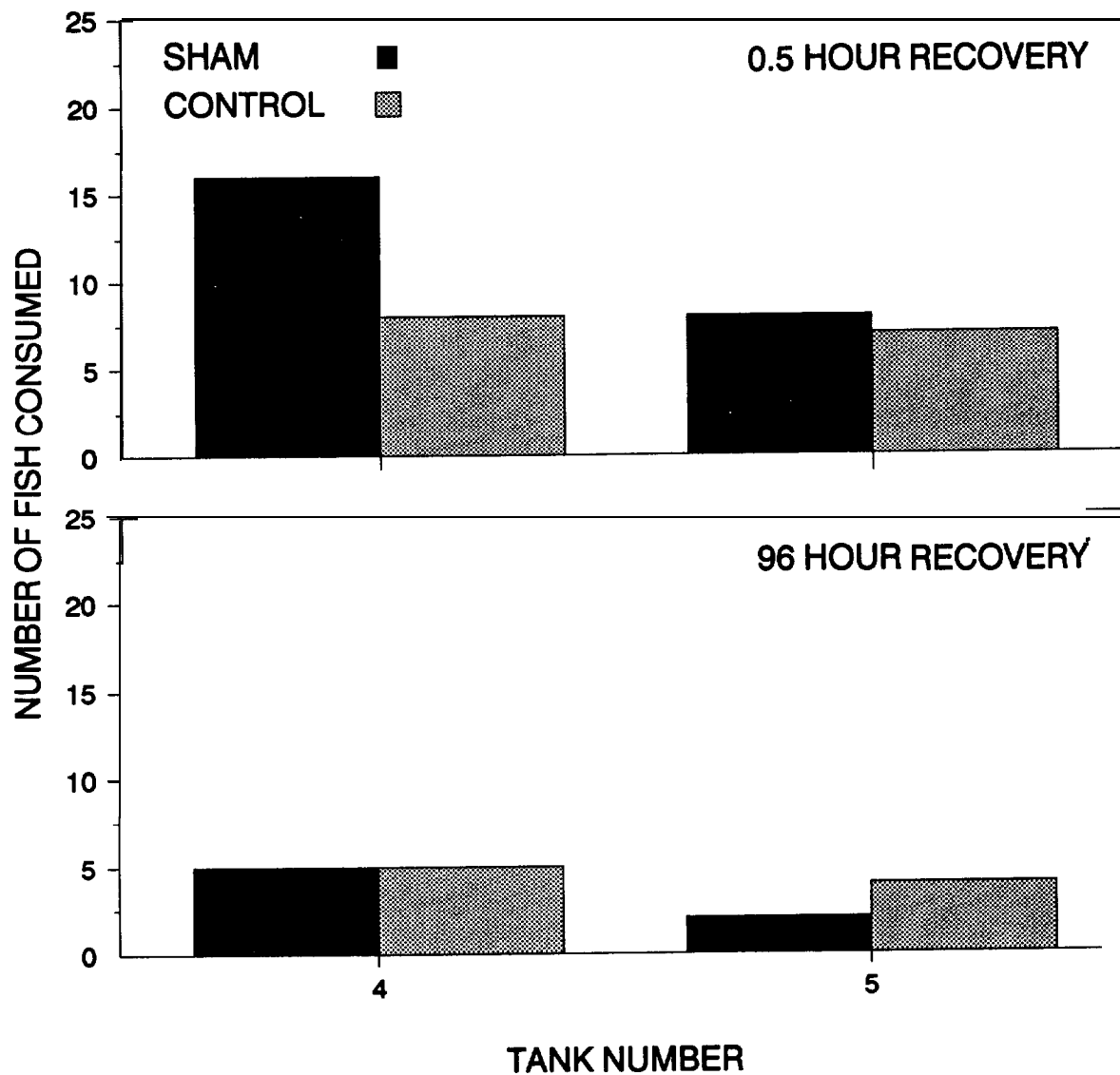
Figure 3. Total number of subyearling chinook salmon eaten in predation vulnerability experiment in which treatment fish were sham tagged. Two recovery periods 0.5 h and 96 h are shown for comparison.

in tank five 8 treatment fish and 7 control fish were consumed.
The heterogeneity chi-square was significant therefore the data
for the two tanks was not pooled. For the 96 h recovery period
tests, 5 treatment and 5 control fish were eaten in tank 4,
while 2 treatment fish and 4 control fish were eaten in tank 5.
The heterogeneity chi-square was significant so that data was not
pooled.

A comparison of mean fork lengths of all PIT-tagged fish
exposed to predation to all surviving PIT-tagged fish showed no
significant difference between groups. Mean size of introduced
PIT tag fish was 59.9 mm (SD = 5.21) while mean size of survivors
was 60.7 mm (SD = 5.28). A Kolmogorov-Smirnov test was used to
compare the size of the PIT tagged survivors to the size of PIT-
tagged fish initially stocked in predation tanks in each trial:
the test showed no significant differences in their cumulative
frequency distributions (P > 0.05). These results suggested
there was no significant relationship between tagged fish size
and vulnerability to predation.

Tag Retention and Delayed Mortality

Tag retention for all groups of PIT tagged fish was greater
than 97% (Table 5). In the first trial of the 1991 experiment
begun on 10 May overall tag retention was 97%, while in the
second trial begun May 17 tag retention improved to over 99%.
Mortality for all groups of treatment fish, including those held
for 96 h predation trials, was 19.7% compared to no mortality for
control groups. In those tanks where treatment fish were held
for tag retention and mortality tests, mortality ranged from 7%
to 27% of the fish stocked in each tank compared to no
mortalities in the control groups (Table 6). During 1992
experiments, over a 90 d holding period, mortality of tagged
fish was 7% while that of control fish held in the same tanks was
6%. Total number of mortalities of tagged fish was 21 while 20
control fish died.

Discussion

The effects of PIT tagging on subyearling chinook salmon
behavior were substantial, but appeared to be short term.
PIT tagging significantly lowered the swimming stamina of fish
allowed only 0.5 h to recover after tagging. PIT-tagged fish
allowed four or more hours to recover performed as well as
control fish in swimming stamina tests.

We assumed that swimming stamina was positively related to
subyearling chinook salmon survival in the natural environment.
Taylor and Foote (1991) found that juvenile sockeye salmon showed
significantly greater mean U-critical swimming velocities than
kokanee and suggested that the divergence was due to a relatively
strong selection for increased swimming stamina in the

Table 5. Percent of PIT tags retained up to 96 h by subyearling chinook salmon tagged on 10 May 1991 (trial 1) and 17 May 1991 (trial 2).

Experiment and trial number	Number of fish PIT tagged	Tag retention	
		Number	Percent
Predation			
0.5 hour recovery			
1	53	51	96
2	64	64	100
96 hour recovery			
1	60	60	100
2	80	79	99
Swim Test			
1	59	57	97
2	64	64	100
Delayed Mortality			
1	81	77	95
2	81	80	99
Cumulative			
1	253	255	97
2	289	287	99

Table 6. Delayed mortality of subyearling chinook salmon PIT tagged on 10 May 1991 (trial 1) and 17 May 1991 (trial 2) and held in tanks compared to mortality in fish neither tagged nor anesthetized (control). Forty fish were held in each tank.

Hours after tagging and trial number	Mortalities and cumulative percent mortality by tank			
	PIT tag	control	PIT tag	control
24				
1	10 (25%)	0	7 (17%)	0
2	11 (27%)	0	3 (7%)	0
48				
1	1 (27%)	0	0	0
2	0	0	0	0
72				
1	0	0	0	0
2	0	0	0	0
96				
1	0	0	0	0
2	0	0	0	0
Cumulative Mortality				
1	11 (27%)	0 (0%)	7 (17%)	O (0%)
2	11 (27%)	0 (0%)	3 (7%)	O (0%)
Total Mortality	22 (27%)	0 (0%)	10 (12%)	O (0%)

anadromous life history. Furthermore, Taylor and McPhail (1985) attributed the greater swimming stamina of juvenile coho salmon *O. kisutch* collected from interior rivers to the greater energetic demands of their longer freshwater migrations. Recently other investigators have demonstrated the trade-off between food supply and swimming cost for drift-feeding salmonids (Hughes and Dill 1990).

Predation on PIT-tagged fish by smallmouth bass indicated that fish allowed 96 h recovery avoided predation significantly better than those provided 0.5 h recovery. We did not test fish with intermediate recovery periods (e.g., 4 h or 24 h) in predation experiments, and therefore it remains to be determined whether vulnerability to predation decreased as rapidly as their swimming stamina improved. However, the high predation rate among tagged groups in 0.5 h recovery predation experiments is consistent with the lower swimming stamina of 0.5 h recovery fish. Considering the high mortality rate of tagged fish, especially in the first 24 h of delayed mortality tests, some fish predated in 0.5 h recovery experiments may have been moribund and therefore easily captured.

Predation vulnerability experiments have demonstrated that fish can recover rapidly from perturbations and re-establish predation avoidance. Other investigators have used the predation tests as a performance challenge to test effects of thermal shock, insecticides, and stress (Hatfield and Anderson 1972: Coutant et al. 1974; Olla and Davis 1989) and several of these investigators have noted improved predator avoidance after recovery times as short as 30 to 90 min (Coutant 1973; Schreck 1981 in Olla and Davis 1989). In studies of juvenile salmon subjected to multiple stressors significant selection by northern squawfish *Ptychocheilus oregonensis* was apparent only in predation tests that lasted 60 min or less (Mesa 1992). Therefore, our observations of increased vulnerability to predation only when allowed 0.5 h to recover from tagging was in agreement with other investigators' findings.

PIT tagging caused high mortality in some of our trials. Prentice et al. (1986) found mortality rate (4%) did not increase significantly in fish as small as 64 mm average fork length. The high mortality rate we observed in 1991 trials, 19.7% overall, might have been due to the relatively small size of the fish tagged, administration of the anesthetic, and tagging technique. During 90 d trials conducted in 1992 mortality was 7% for treatment fish and 6% for controls. The results suggested PIT tagging contributed to one percent of the mortality experienced by all fish held in the tanks. We attribute this substantial reduction in mortality of tagged subyearling chinook salmon to the use of buffered anesthetic and improved tagging techniques. Other investigators have found that buffered anesthetic can

result in reduced mortality when using soft water (Wedemeyer 1970; Soivio et al. 1977; Sylvester and Holland 1982). The combination of anesthetizing too many fish at one time and the relatively slow rate of PIT-tagging with a syringe are more likely the cause of high mortality in earlier experiments.

Initially we assumed that our inexperience with tagging relatively small fish may have attributed to the high post tagging mortality. However, training tests with an inexperienced person contradict that assumption since 4% mortality was observed. The tagging technique is very important for relatively small fish. Prentice et al. (1990b) indicated that once the needle passes through the body wall musculature, the needle angle is changed and then inserted farther until its point is posterior to the pyloric caecae near the pelvic girdle. However, we found that after the needle passes through the body wall, it can be backed out and the tag inserted into the body cavity resulting in less internal intrusion with a sharp needle and higher tag retention.

The validity of migration timing data of the Snake River subyearling chinook salmon relies on whether or not tagged fish behave in a manner similar to the non-tagged fish. This question can only be partially answered by laboratory experiments. Knowing the effects of tagging on swim performance and predation vulnerability is not equivalent to knowing the effects of tagging on such specialized behavior as migration timing. However, these tests do indicate that some behavior, for example predator avoidance, may not be affected if PIT-tagged fish are allowed an adequate recovery period. Further experimentation will be done to determine the minimum time necessary for tagged fish to recover so that they are no more vulnerable to predation than controls. These experiments should indicate the profundity of impact that PIT tagging has on the behavior of subyearling chinook salmon.

Conclusions

1. A comparison of U-critical swimming speed of PIT tagged and control fish allowed to recover for time periods ranging from 0.5 h to 96 h indicated that any effects from tagging on swimming performance are relatively short term, probably 4 h or less.

2. Pit tagged subyearling chinook salmon exposed to predation by smallmouth bass were consumed at a higher rate compared to a control group when fish were allowed a 0.5 h recovery time, but the number of tagged and control fish consumed were similar when allowed a 96 h recovery period before predation risk.

3. Sham-tagged fish and control fish were not preyed upon at significantly different rates suggesting that the presence of the

PIT tag contributes to the higher predation rates on treatment fish.

4.   Predation of PIT-tagged fish was not size selective based on the comparison of the size of PIT-tagged fish stocked into predation tanks versus the size of fish surviving the tests.

5.   Delayed mortality of PIT-tagged fish ranged from 7% to 27% and occurred primarily in the first 24 h after tagging. Subsequent experiments with a rearing period of *90* d indicate a *1%* mortality rate attributable to PIT tagging.

6.   Other factors that we believe contributed to relatively high mortality of subyearling chinook salmon were tagging technique and most importantly the application of anesthetic. Use of buffered anesthetic and shorter total exposure times for anesthetic may be critical factors in reducing mortality.

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CHAPTER FIVE

Rearing and Emigration of Naturally Produced
Snake River Fall Chinook Salmon Juveniles

by

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Introduction

Minimal data are available on the rearing and emigration of juvenile Snake River fall chinook salmon *Oncorhynchus tshawytscha*. In 1991, when the National Marine Fisheries Service was petitioned to list Snake River fall chinook salmon under the Endangered Species Act of 1973 (ESA; United States Fish and Wildlife 1988), most information on these subyearling emigrants was either outdated or based on conjecture. The data that are available were collected during studies involving hydroelectric dams and chinook salmon populations in the Snake River.

The construction of Brownlee Dam in 1957 inspired a number of studies and unsuccessful attempts to preserve wild fall chinook salmon production in the middle Snake River (Graban 1964). The upstream bypass of adult fall chinook salmon and downstream trapping of juveniles past Brownlee Dam was discontinued by 1964 (Richards, in Armour 1990).

Oxbow Dam, located down river of Brownlee Dam, was completed in 1961. In 1963, Oxbow Hatchery became fully operational and all the fall chinook salmon adults that returned to Oxbow Dam were spawned (Haas 1965). Fall chinook salmon juveniles reared in Oxbow Hatchery were released directly into the Snake River below Oxbow Dam. One inevitable outcome of these juvenile fall chinook salmon releases was the mixing of remnant wild salmon with salmon of hatchery origin. When hatchery fish spawn with wild fish in natural stream settings, we refer to the progeny as being naturally produced.

By 1967, when Hells Canyon dam was completed, natural fall chinook salmon spawning was restricted to what remained of the free-flowing Snake River. The first evidence of naturally produced fall chinook salmon juveniles below Hells Canyon Dam Was reported in 1974 when button-up fry were stranded in late March during a rapid flow decrease provided for river gaging (K. Witty, Oregon Department of Fish and Wildlife, personal communication; Bayha 1974). The discontinuation of hatchery releases of fall chinook salmon into the Snake River above Lower Granite Dam in 1985 (Roseberg et al. 1992), meant that continued production in the free-flowing river relied on returning adults of natural origin. Natural fall chinook salmon production has continued through 1991, as evidenced by redd counts (summarized by Connor et al. 1993 in this report) and incidental collections of button-up chinook salmon fry at a smolt trap near the interface of the free-flowing Snake River and Lower Granite Reservoir (E.W. Buettner, Idaho Department of Fish and Game, personal communication). Captures of presumed fall chinook salmon juveniles have been recorded in Lower Granite and Little Goose reservoirs each spring since 1990 by University of Idaho

investigators (Bennett et al. 1991). Collectively, the above three encounters provide the basis for our contemporary understanding of naturally produced Snake River fall chinook salmon juveniles.

The purpose of our research is to increase the information on naturally produced Snake River fall chinook salmon juveniles for ESA recovery planning (United States Fish and Wildlife 1988). Our 1991 work was intended to be a pilot study, but at the request of the fisheries agencies and tribes of Idaho, Oregon, Washington and the National Marine Fisheries Service (NMFS) we increased our effort to accomplish and report on the following objectives: (1) determine the feasibility of using beach seines to capture chinook salmon juveniles in the free-flowing Snake River: (2) develop criteria to separate the seine catch into naturally produced Snake River fall chinook salmon juveniles and juvenile subyearling spring/summer chinook salmon: (3) describe the early life history and emigration timing of naturally produced Snake River fall chinook salmon; and 4) develop techniques to estimate the influence of juvenile fish size, water flow, and water temperature on emigration rate.

study Area

The study area included the Snake River from Hells Canyon Dam to Lower Granite Dam (Figure 1). In 1991, we gathered data by seining and tagging juvenile chinook salmon in a reach bounded by Red Bird Creek at river kilometer (RK) 250 and the upper end of Lower Granite Reservoir (RK 211); within this reach we seined 10 different sites. Mean daily Snake River discharge at the United States Geological Survey gage at Anatone, Washington (RK 270) ranged from approximately 67,300 to 14,600 cubic ft/s (CFS) during sampling (Figure 2). Mean daily water temperature collected at Billy Creek (RK 265) ranged from approximately 11.6 to 22.2°C during sampling (Figure 2).

Methods

Data Collection

Seining-Ten sites were seined 2 or 3 times per week from 28 May until 17 July, 1991. Chinook salmon were captured in a 0.32 cm mesh beach seine measuring 21.3 m x 1.2 m with a 1.7 m^3 bag and a weighted multistranded mudline. Each end of the seine was fitted with a 1.2 m bottom weighted brail and 15.2 m lead ropes. The seine was set parallel to shore from the stern platform of a 6.7 m jet boat. The net was then hauled straight into shore by both lead ropes. This technique sampled approximately 323 m^2 of river to a depth of 1.2 m. When necessary, we modified this
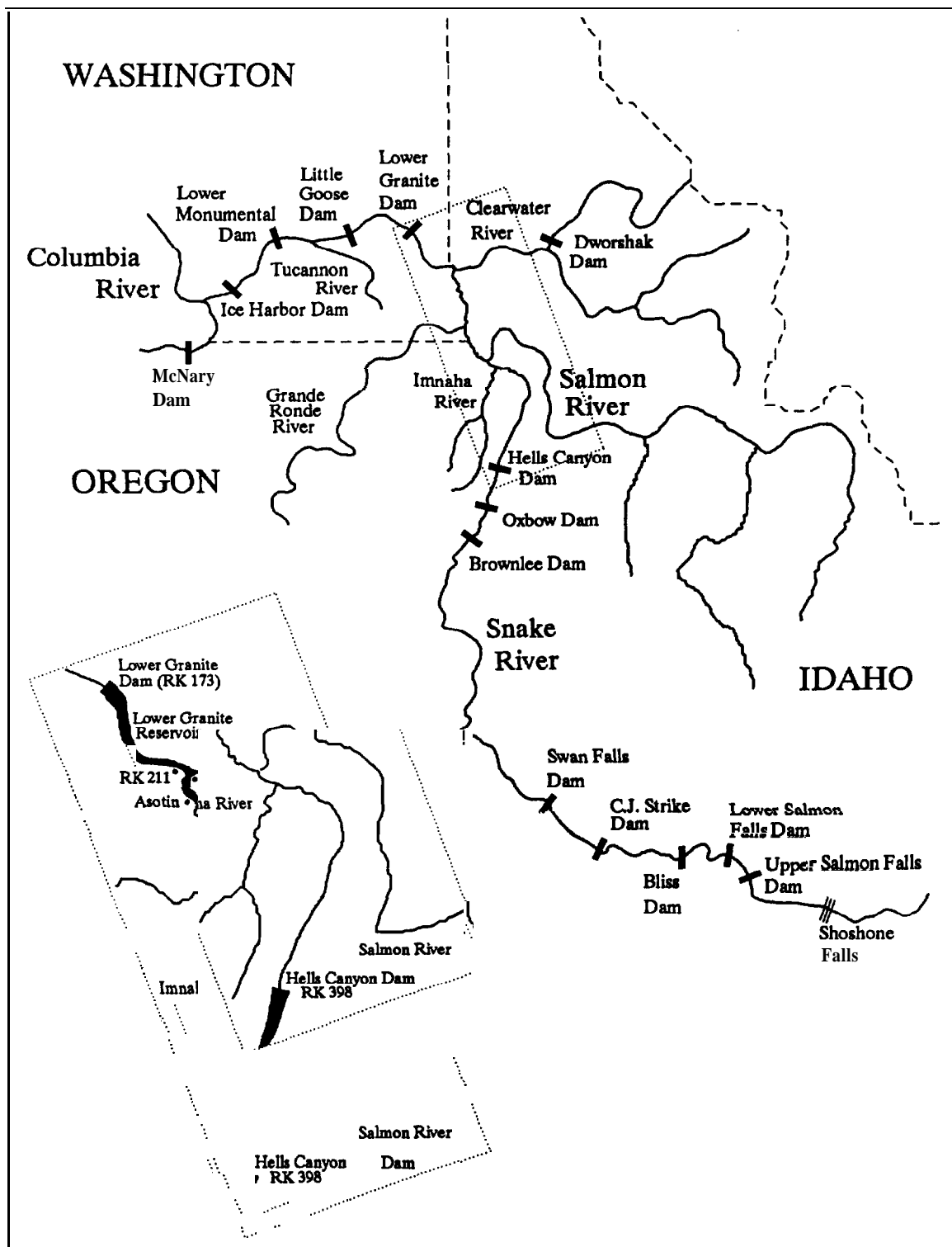
Figure 1. Map of the Snake River drainage with an insert to show the 1991 seining area boundaries of **RK** 211 and RK **250.**
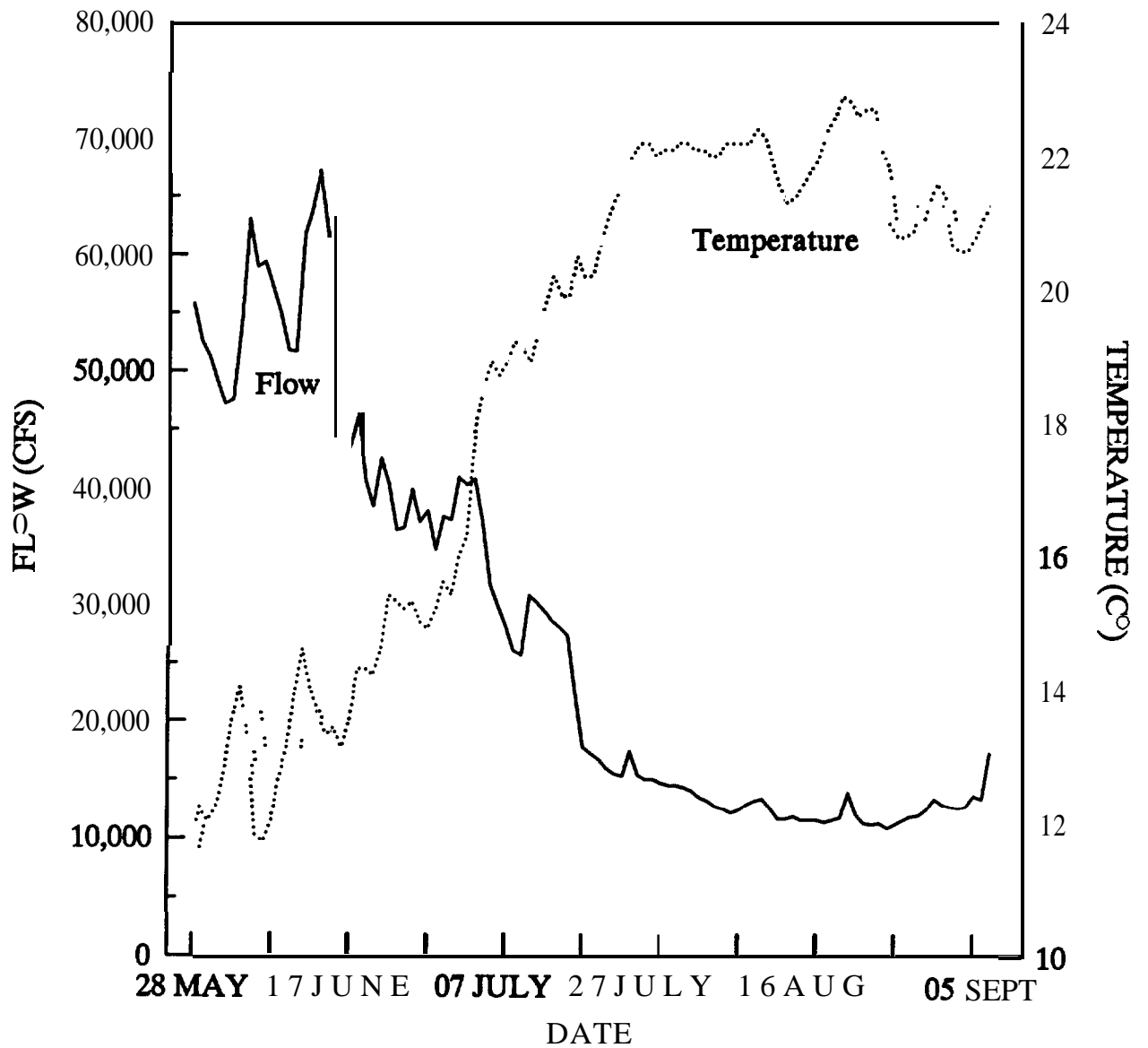
Figure 2. Mean daily flows (RK 270) and temperatures (RK 265) in the Snake River during the 1991 seining, PIT tagging, and naturally produced fall chinook salmon juvenile dispersal, rearing and emigration seasons.

approach to accommodate the physical features of a given site.

Anesthesia- Once seined, chinook salmon were transferred to an oxygenated live-well supplied with water at river temperature. All chinook salmon were anesthetized in a dilute MS-222 solution of 45 mg/L water in groups of 6-10 fish. Fork lengths of anesthetized chinook salmon juveniles were measured to the nearest millimeter.

PIT tagging.-The minimum size limit for PIT tagging (Prentice et al. 1990a) chinook salmon was 55 mm fork length. We arrived at this size through discussion with NMFS personnel (E. Prentice, National Marine Fisheries Service, personal communication) and by experimentation with Columbia River upriver bright fall chinook salmon of hatchery origin (McCann et al. 1993 in this report).

In-season race identification.-We knew that our seine catch would contain fall, spring, and summer race chinook salmon juveniles. Therefore, we calculated an upper size limit to identify fall chinook salmon juveniles "in-season" for tagging since they are smaller than yearling spring or summer chinook salmon. We calculated the size limit based on water temperature, fry emergence timing, and projected growth rate.

Water temperature data for the size limit calculation were collected below Hells Canyon Dam (RK 398) and Billy Creek (RK 265). These temperature data were used to estimate fry emergence, believed to occur 850 Celsius temperature units (CTUs; modified from Piper et al. 1982) after spawning. For the size limit calculation, emergent fry were estimated to be 38 mm fork length (Arnsberg et al. 1992), and estimated to have a growth rate of 0.82 mm/monthly CTU (0.5 mm/d; T. Frew, Idaho Department of Fish and Game, personal communication). Growth rate had to be calculated separately for chinook salmon juveniles collected above and below the Salmon River confluence because of differences in water temperature. We produced the upper fall chinook salmon size limit in Table 1 using water temperatures from below the Salmon River. The lower fall chinook salmon size limit in Table 1 was calculated using the 55 mm minimum size for tagging and water temperatures from above the Salmon River.

Table 1. Upper and lower size limits calculated for in-season race identification of chinook salmon seined in the Snake River, 1991.

Limit	Estimated fall chinook salmon size by date								
	21-May	28-May	4-Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul
Upper	70	73	76	78	81	84	87	89	92
Lower	55	55	55	55	55	58	61	64	66

From 28 May to 12 June, 1991 we only PIT tagged chinook salmon juveniles that fell within the size limit of Table 1. During tagging, chinook salmon juveniles were immobilized by placing them in a notched foam pad kept wet and cool. Tags were manually implanted with a 12 gauge needle affixed to a syringe. Tags and needles were disinfected with alcohol or iodine. After tagging, we swabbed the insertion wound with a dilute iodine solution then transferred the fish to an oxygenated recovery tank for 15-30 min prior to release. All tagged chinook salmon juveniles were released where they were captured.

After two weeks of seining and PIT tagging chinook salmon juveniles, sharper body features and smaller eyes were noted in some groups of fish. We believed the above differences in morphology were related to fish race. Consequently, we adopted fish morphology as a secondary form of in-season chinook salmon race identification. On 13 June, we began tagging fish with juvenile fall chinook salmon morphology if they were at least 55 mm long. Note that in 1991, we did not count, measure, or tag any fishes, that did not meet size limits or look like fall chinook salmon juveniles.

*PIT tag data.-*The data collected from the PIT-tagged chinook salmon juveniles were recorded in computer files (PIT Tag Work Group 1991). These tagging files were uploaded to the PIT Tag Information System (PITAGIS). Emigrating chinook salmon juveniles that bypass Lower Granite Dam turbines via the submersible travelling screen are monitored for PIT tags (Prentice et al. 1990b). Both PIT-tagging and PIT-tag detection data are available to interested parties through PITAGIS).

Electrophoresis.- A subsample of the PIT-tagged chinook salmon detected at Lower Granite Dam are diverted by a hydraulic slide gate. Diverted chinook salmon are scanned for tag codes and measured by Smolt Monitoring Program (SMP) personnel. When our tag codes were detected in chinook salmon that measured at least 100 mm fork length, a scale sample was taken for aging (Jerald 1983). The fish was then labeled and frozen. When our tag codes were detected in chinook salmon that were smaller than 100 mm fork length the fish was reared on site. After rearing to 100 mm fork length, the fish was handled as described above. The Washington Department of Fisheries (WDF) validated the race of the frozen chinook salmon using tissue extracts and horizontal starch-gel electrophoresis (Abbersold et al. 1987).

Data Analysis

Overall tagging.-The first step in our analysis was a description of beach seine catches of all the juvenile chinook salmon we PIT tagged.

Post-season race separation.- We used a simple process to separate out spring\summer chinook salmon data from fall chinook salmon data. We based this "post-season" race separation process on data collected from the tagged electrophoretically validated fall chinook salmon juveniles diverted at Lower Granite Dam. Growth rates for the above fall chinook salmon juvenile were calculated by subtracting salmon size at tagging (release size) from size at diversion and dividing by the time the fish was at large. Individual growth rates were used to back calculate the emergence date of each fall chinook salmon, assuming an emergence size of 38 mm. We then calculated post-season size limits using growth rates of the earliest and latest emerging salmon that were validated as Snake River fall chinook salmon by electrophoresis.

We applied the post-season size limit to the lengths of all the chinook salmon juveniles we PIT tagged. Chinook salmon juveniles that fit the post-season size limit were considered to be Snake River fall chinook salmon.

Emigration rate.- We calculated emigration rate separately for each PIT-tagged fall chinook salmon by determining the distance between the release site and Lower Granite Dam and dividing by the time the fish was at large before being detected at the dam. Linear regression (SYSTAT 1990) was used to describe the relation between fall chinook salmon release size and emigration rate (Appendix 6).

Multiple General Linear Hypothesis testing (MGLH; Systat 1990) was used to test for relations between and among fall chinook salmon emigration rate and size at release, Snake River

average discharge at Lower Granite Dam when the fish was at large, the Snake River average water temperature when the fish was at large, and Snake River water temperature the moment the fish was released (Appendix 7).

To explore the hypothesis of a minimum fall chinook salmon juvenile emigration size, we adjusted our data for each PIT-tagged fall chinook salmon detected at Lower Granite Dam to 5 mm size increments between 55 and 95 mm. Data adjustment involved three steps that reduced the time at large of each fall chinook salmon depending on the salmon's size at PIT tagging. These steps were: 1) all fall chinook salmon that were at least as long as the given 5 mm increment at tagging were considered to be active migrants so no adjustments were made in their individual value for time at large; 2) for the remaining fall chinook, time at large was reduced by the number of days it would take the fish to grow to the 5 mm increment; and 3) using the time at large values from both steps 1 and 2, we calculated emigration rate, average flow at Lower Granite Dam during emigration (emigration flow), and average water temperature in the Snake River during emigration (emigration temperature). After steps 1-3 above, we we regressed emigration rate against emigration flow and emigration temperature using the data produced for each 5 mm increment.

In the regression analysis we assumed the data from the 5 mm increment that maximized the r^2 value would be representative of the size range of fall chinook salmon at emigration. We also believed that the adjusted data for this 5 mm increment would more accurately represent the correlation between emigration rate, flow, and temperature than unadjusted data.

Results

Overview of PIT tagging Chinook Salmon Juveniles

We PIT tagged 738 chinook salmon juveniles between 28 May and 17 July, 1991 (Figure 3). The peak of tagging occurred on 25 June. We tagged chinook salmon juveniles between RK 211 and RK 250 with most tagging occurring at RK 242 (Figure 4). Tagged chinook salmon juveniles ranged in fork length from 55 mm to 120 mm (Figure 5).
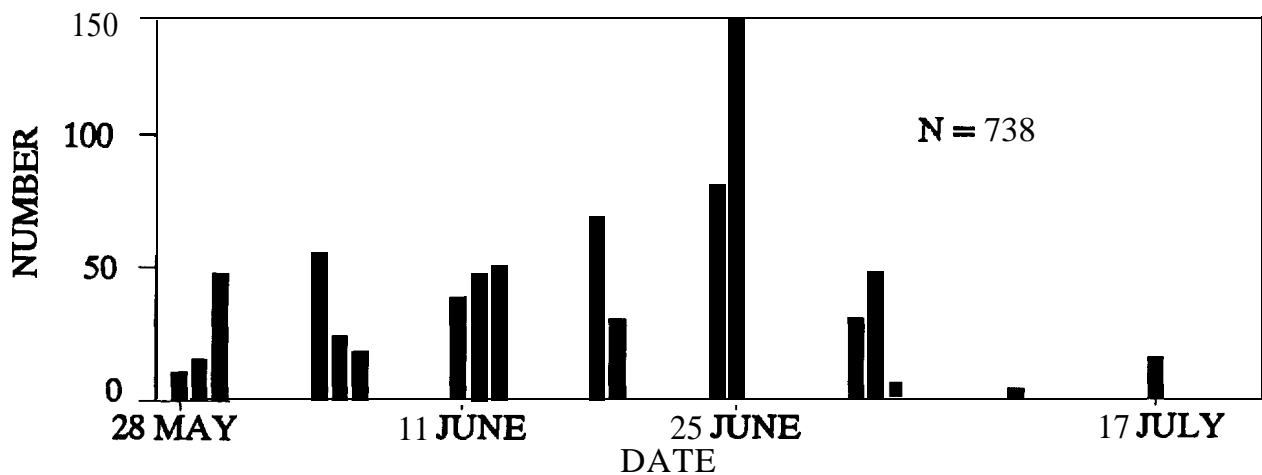
Figure 3. Number of chinook salmon juveniles PIT tagged by date in the Snake River between river kilometer 211 and 250,1991.
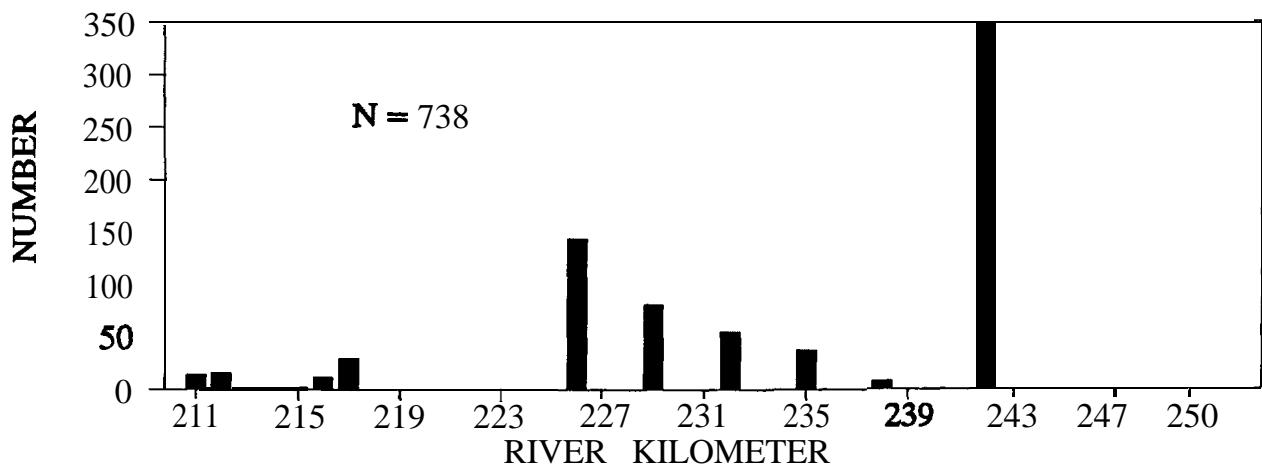
Figure 4. Number of chinook salmon juveniles PIT tagged by river kilometer in the Snake River, 28 May to 17 July, 1991.
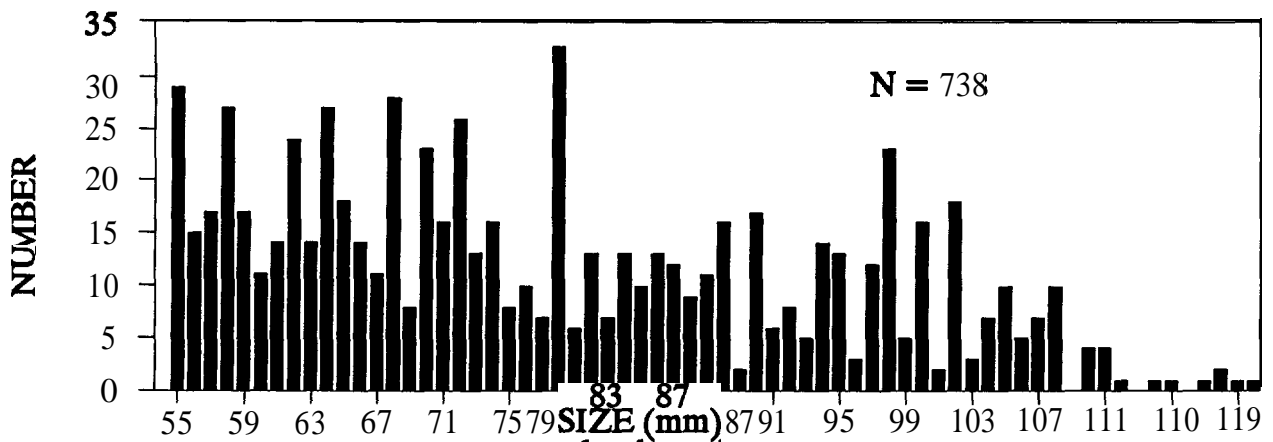
Figure 5. Length frequency of chinook salmon juveniles PIT tagged in the Snake River between RK 211 and RK 250,28 May to 17 July, 1991.

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Post-season Separation of Fall and Spring/Summer Chinook Salmon Juveniles

A total of 74 of the chinook salmon juveniles we PIT tagged were detected at Lower Granite Dam, of which 57 were diverted by the sliding gate. Forty-nine of the diverted fish were analyzed by electrophoresis (Table 2). Electrophoresis validated 46 as fall and 3 as spring\summer chinook salmon. All fall and spring\summer chinook salmon juveniles were age 0 fish. The 42 fall chinook salmon juveniles that were measured grew an average of 1.4 mm/d (SD + 0.2 mm/d; range 0.8-1.9 mm/d). Spring/summer chinook salmon growth averaged 1.0 mm/d (SD $\pm$ 0.1 mm/d; range 0.8-1.2 mm/d).

The back calculated emergence dates for electrophoretically validated fall chinook salmon juveniles ranged from 4 April (tag code 7F7D075374) to 4 June (tag code 7F7D15310C) with peaks on 17 and 23 May (Table 2; Figure 6). The post-season size limit based on the emergence dates and growth rates of fall chinook salmon 7F7D075374 and 7F7D15310C (Table 2) provided a fairly accurate method to separate the data by chinook salmon race (Figure 7). Applying the post-season size limit to the fork lengths of the 738 juvenile chinook salmon we had PIT tagged separated out 650 fall chinook salmon (Figure 8).

PIT-tagged Fall Chinook Salmon Emergence, Rearing, and Emigration

Back calculated emergence timing **estimates** for the 650 PIT-tagged fall chinook salmon range from 4 April to 13 June with a peak emergence on 23 May (Figure 9).

We PIT tagged the 650 fall chinook salmon between 28 May and 17 July, 1991 (Figure 10). The number of fall chinook salmon tagged per day ranged from 1 to 114 fish. The peak of fall chinook salmon tagging occurred on 25 June. Fall chinook salmon were tagged between RK 211 and RK 250; most tagging occurred at RK 242 (Figure 11).

We recaptured 53 PIT-tagged fall chinook salmon once and 10 twice (Table 3). Recapture interval ranged from 1 to 26 days. Only one salmon, which swam upriver 3 km, was recaptured away from its original site of capture.

Table 2. Data for chinook salmon juveniles PIT tagged in the Snake River, diverted at Lower Granite Dam, and analyzed by electrophoresis, 1991.

Tag code	Release date	Release size (mm)	Detection date	Size at detection (mm)	Days at large	Race	Age	Growth rate (mm/d)	Back calculated date of emergence
7F7D075374	06/18/91	98	07/09/91	115	21.1	Fall	o	0.8	04 04/91
7F7D153B00	06/25/91	108	07/09/91	120	13.5	Fall	o	0.9	04/08/91
7F7D074C21	06/25/91	106	07/20/91	131	24.4	Fall	o	1	04/18/91
7F7D1E4750	06/13/91	98	07/18/91	136	35.6	Fall	o	1.1	04/19/91
7F7D1D5960	06/18/91	94	06/30/91	109	12.2	Fall	o	1.2	05/02/91
7F7D1D5621	06/18/91	97	07/18/91	138	30.6	Fall	o	1.3	05/04/91
7F7D165111	06/25/91	102	07/11/91	124	16.4	Fall	o	1.3	05/07/91
7F7D152E70	06/25/91	91	08/11/91	142	47.0	Fall	o	1.1	05/08/91
7F7D07537C	06/18/91	99	07/08/91	129	19.7	Fall	o	1.5	05/08/91
7F7D152E2E	06/25/91	104	07/25/91	147	30.0	Fall		1.4	05/09/91
7F7D152A3C	06/25/91	98	07/25/91	137	29.8	Fall		1.3	05/10/91
7F7D075937	06/18/91	84	08/01/91	139	44.2	Fall	o	1.2	05/11/91
7F7D1E6855	05/30/91	64	07/15/91	127	46.0	Fall		1.4	05/11/91
7F7D1E4C28	05/30/91	58	08/06/91	140	68.3	Fall	o	1.2	05/13/91
7F7D1E3C3E	06/04/91	68	07/18/91	133	44.9	Fall	o	1.4	05/14/91
7F7D1E4207	07/02/91	102	07/20/91	126	17.8	Fall	o	1.3	05/14/91
7F7D15311A	06/25/91	97	07/24/91	138	28.5	Fall	o	1.4	05/14/91
7F7D1D6846	06/11/91	70	06/30/91	94	19.3	Fall	o	1.2	05/15/91
7F7D1E3A6F	06/11/91	78	07/21/91	137	40.0	Fall	o	1.5	05/15/91
7F7D154221	06/25/91	94	07/24/91	135	28.8	Fall		1.4	05/16/91
7F7D165972	06/25/91	97	07/20/91	135	25.2	Fall	o	1.5	05/17/91
7F7E342416	07/01/91	106	07/20/91	134	19.0	Fall	o	1.5	05/17/91
7F7D1E5172	06/12/91	72	07/30/91	132	46.6	Fall		1.3	05/17/91
7F7D07502A	06/24/91	95	07/22/91	137	27.7	Fall		1.5	05/17/91
7F7D165E31	06/25/91	90	07/25/91	130	29.5	Fall	o	1.4	05/19/91
7F7D1E3C57	07/01/91	96	07/24/91	129	23.0	Fall		1.4	05/21/91
7F7D1E4569	06/06/91	56	08/10/91	134	66.2	Fall	ooo	1.2	05/22/91
7F7D16402F	06/25/91	88	07/15/91	118	19.7	Fall		1.5	05/23/91
7F7D074606	06/24/91	83	07/28/91	131	34.1	Fall		1.4	05/23/91
7F7D074E51	06/19/91	81	07/25/91	137	35.4	Fall		1.6	05/23/91
7F7D1E4071	06/11/91	64	07/25/91	124	42.2	Fall		1.4	05/23/91
7F7D1E4651	06/11/91	67	07/21/91	131	40.4	Fall	o	1.6	05/24/91
7F7D1E5101	06/13/91	70	07/23/91	133	39.9	Fall		1.6	05/24/91
7F7D165D76	06/25/91	87	07/24/91	132	29.0	Fall		1.6	05/25/91
7F7D152B0A	06/25/91	80	07/23/91	120	27.9	Fall		1.4	05/26/91
7F7D154618	06/25/91	84	08/02/91	134	31.3	Fall	o	1.6	05/27/91
7F7D075869	06/24/91	74	07/31/91	121	36.7	Fall	o	1.3	05/27/91
7F7E355201	07/02/91	103	07/10/91	118	7.8	Fall		1.9	05/29/91
7F7D1D5821	06/18/91	70	07/25/91	127	36.5	Fall	o	1.6	05/29/91
7F7D07513C	06/24/91	82	07/13/91	113	18.5	Fall	o	1.7	05/29/91
7F7D152A19	06/25/91	75	07/27/91	123	31.9	Fall	o	1.5	05/31/91
7F7D15310C	06/25/91	72	08/03/91	123	31.1	Fall	o	1.6	06 04/91
7F7D1E3B35	06/04/91	55	09/05/91	---	84.4	Fall	o	---	---
7F7D1E3071	06/13/91	94	06/28/91	---	14.6	Fall	o	--	---
7F7D165976	06/25/91	72	07/25/91	---	30.0	Fall		--	---
7F7D074E6F	06/24/91	94	06/29/91	---	4.5	Fall	o	--	---
7F7D164654	06/25/91	107	07/10/91	121	14.8	Spring\summer	o	0.J	---
7F7E1D3B08	07/01/91	119	07/06/91	123	4.8	Spring\summer	o	0.J	---
7F7D07474F	06/24/91	100	07/09/91	117	14.7	Spring\summer	o	1.J	---

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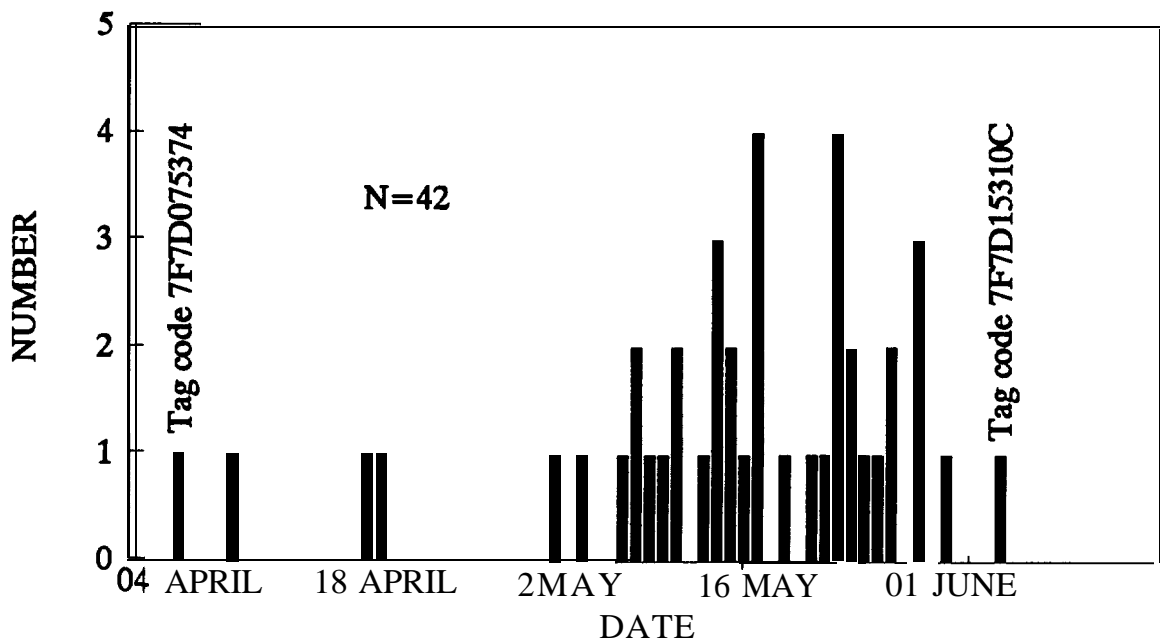
Figure 6. Back calculated emergence dates of PIT-tagged salmon shown by electrophoresis to be Snake River fall chinook, after being diverted at Lower Granite Dam, 1991. Data from the tag codes in this figure are used to calculate the "post-season" size limit in Figure 7.

Figure 7. Testing the applicability of the "post-season" size limit using chinook salmon juveniles which were seined and PIT tagged in the Snake River, diverted at Lower Granite Dam and subjected to eletrophoresis, 1991. The tag codes are from the earliest and latest emerging fall chinook salmon in Table 2.
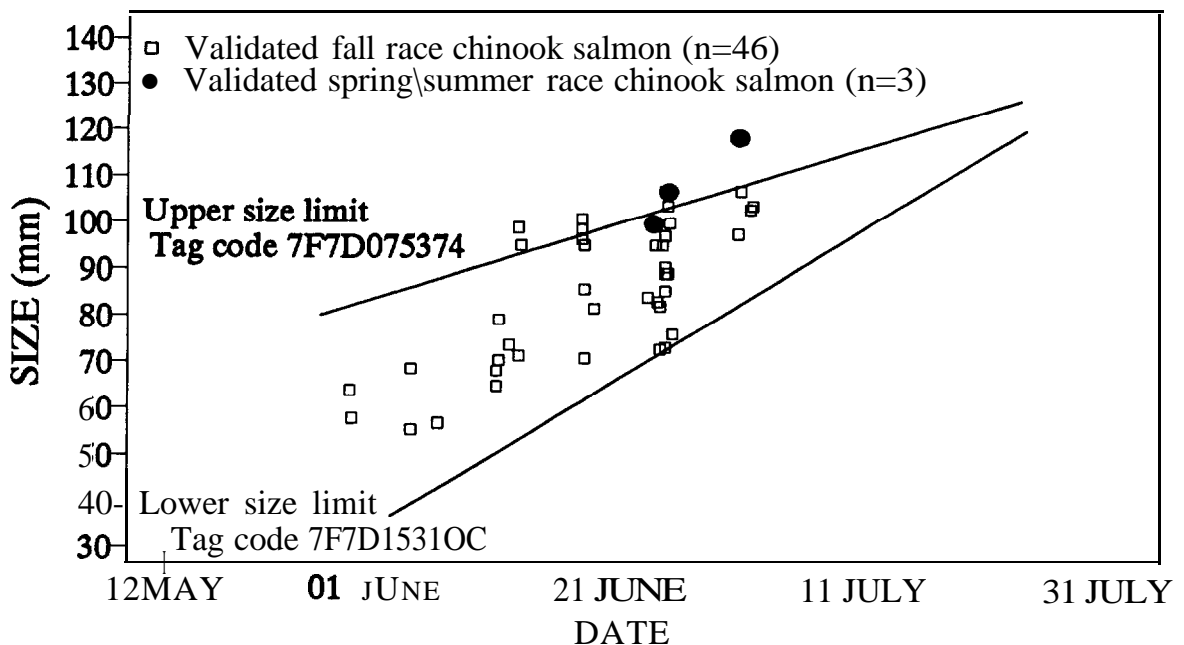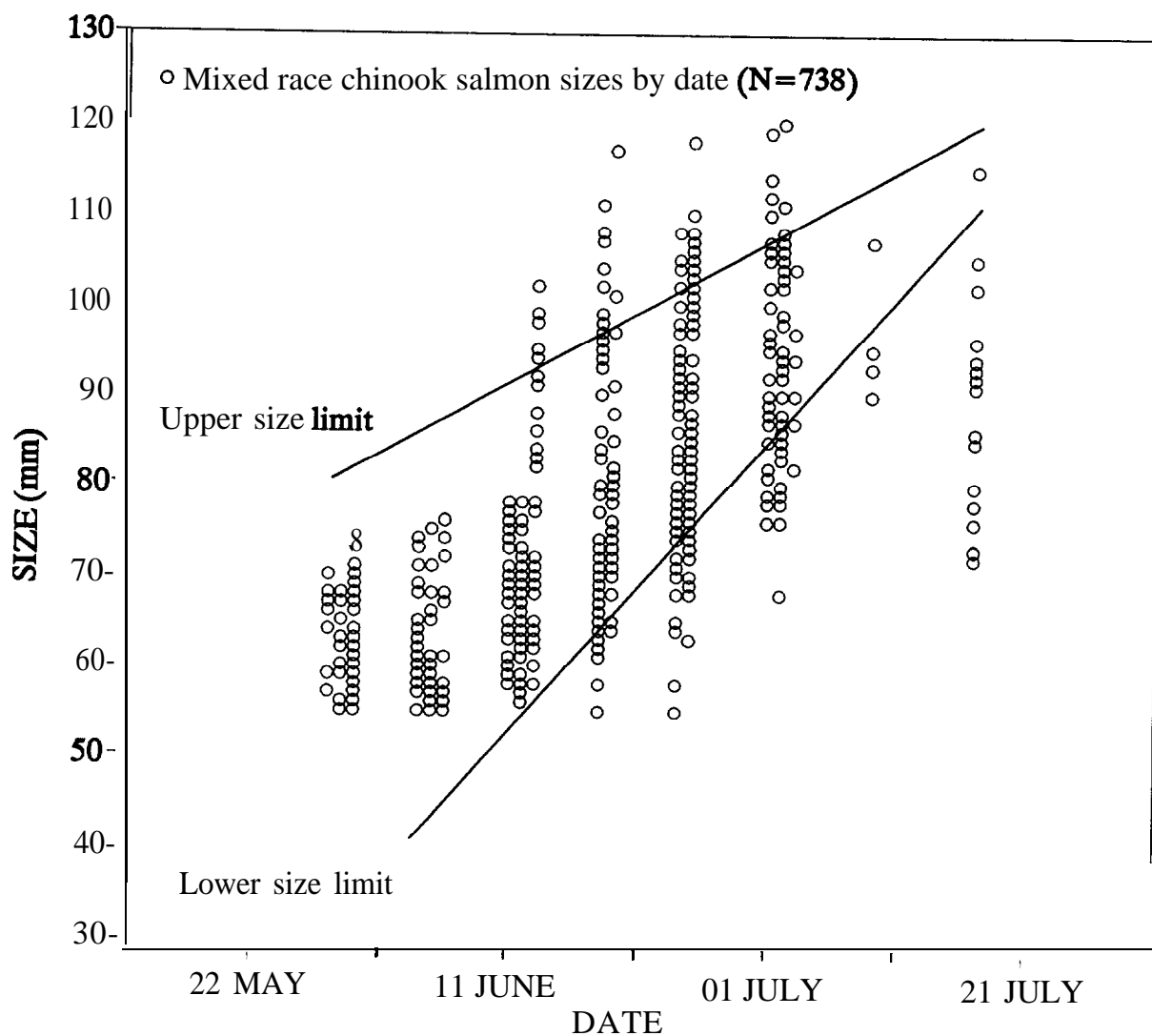
Figure 8. Separating Snake River fall chinook salmon juveniles from juveniles of
of mixed race using the "post-season" size limit. Of 738 lengths, 650 are
are within the size range of fall chinook salmon.
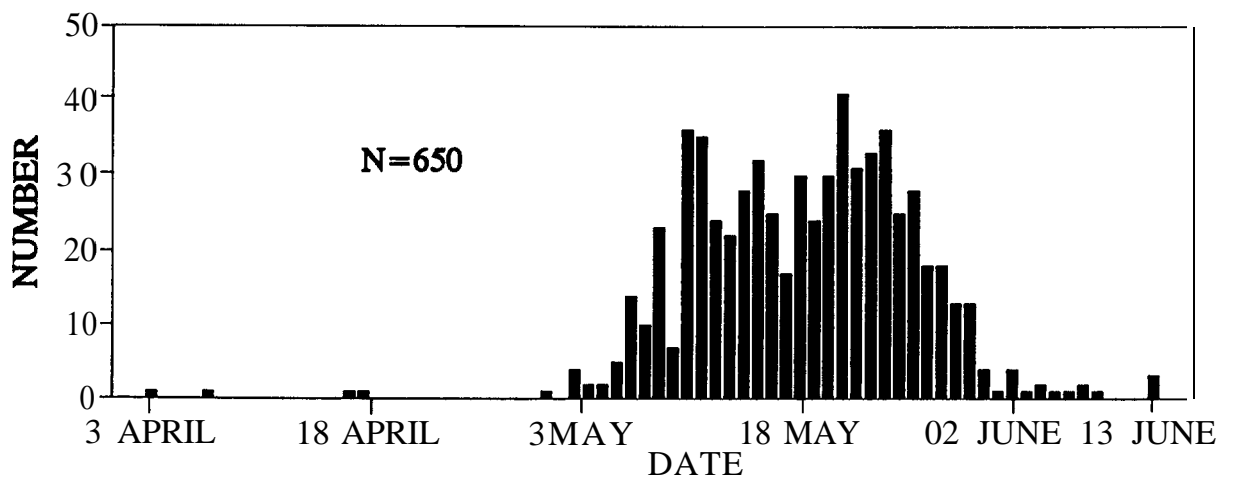
Figure 9. Snake River fall chinook salmon emergence timing in 1991 back calculated usmg the release size of each fish, individual growth rates or the average growth rate of 1.4 mm/d, and a fry emergence size of 38 mm.
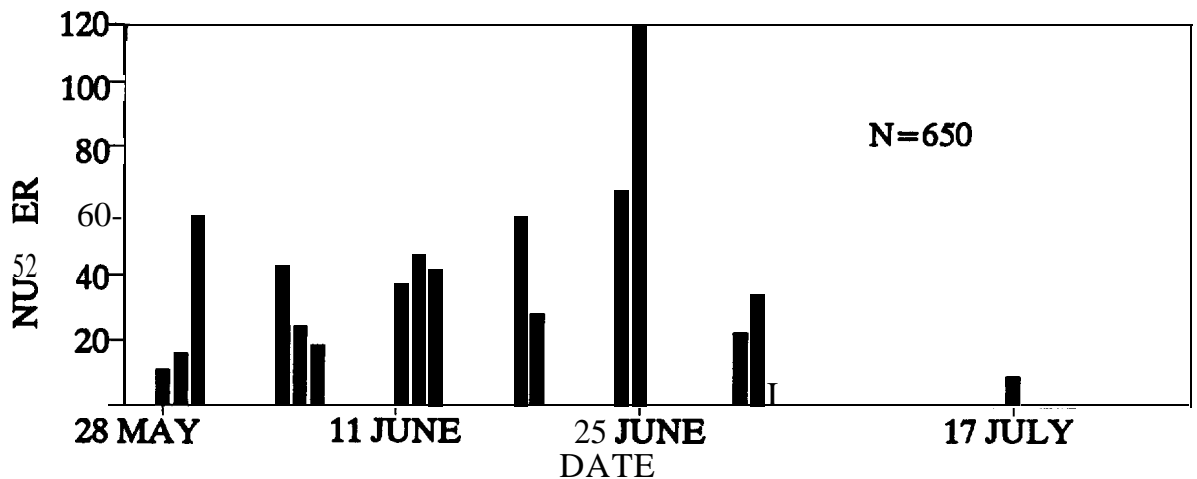
Figure 10. Number of fall chinook salmon juveniles PIT tagged by date in the Snake River between river kilometer 211 and 250,1991.
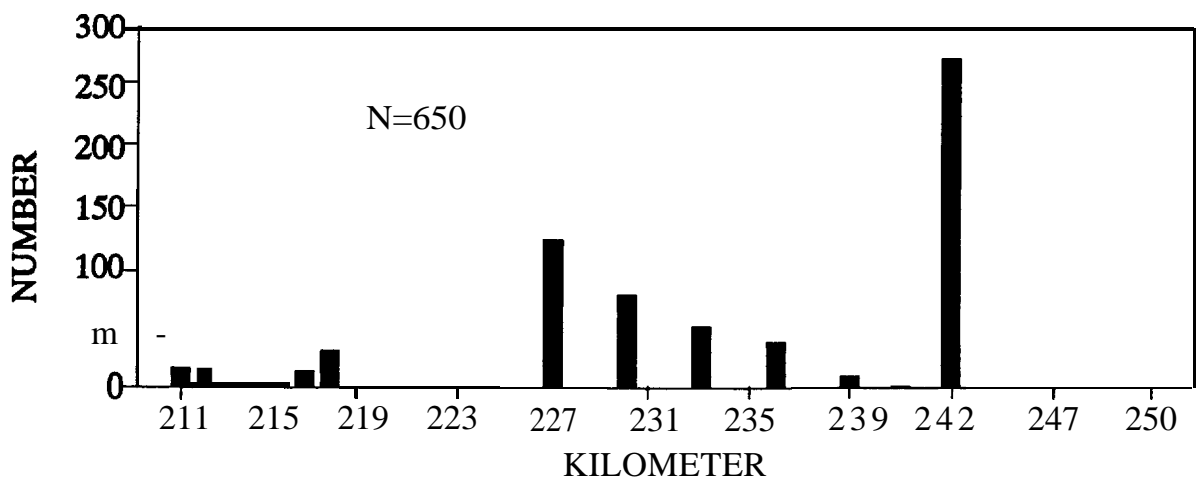
Figure 11. Number of Snake River fall chinook salmon juveniles PIT tagged by river kilometer, 1991.

Table 3.   Beach seine recoveries of PIT-tagged naturally produced fall chinook salmon juveniles recaptured in the Snake River, 1991.

Recapture event	Release site	Recapture site	Date released	Date recaptured	Time interval between capture events	Kilometers travelled
First	217	217	05/29/91	05/30/91	1	0
	229	229	05/30/91	06/04/91	5	0
	229	229	05/30/91	06/12/91	13	0
	229	229	05/30/91	06/04/91	5	0
	229	229	05/30/91	06/04/91	5	0
	229	229	05/30/91	06/04/91	5	0
	229	229	05/30/91	06/04/91	5	0
	235	235	06/04/91	06/11/91	7	0
	235	235	06/04/91	06/11/91	7	0
	235	235	06/04/91	06/12/91	8	0
	235	235	06/04/91	06/12/91	8	0
	235	235	06/04/91	06/12/91	8	0
	229	229	06/06/91	06/13/91	7	0
	242	242	06/06/91	06/25/91	19	0
	242	242	06/06/91	06/24/91	18	0
	229	232	06/06/91	06/11/91	5	3
	229	229	06/11/91	06/13/91	2	0
	242	242	06/11/91	07/02/91	21	0
	226	226	06/12/91	06/13/91	1	0
	226	226	06/12/91	06/13/91	1	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0
	232	232	06/18/91	06/24/91	6	0
	242	242	06/18/91	06/24/91	6	0

TABLE 3. (CONTINUED)

Recapture event	Release site	Recapture site	Date released	Date recaptured	Time between capture events	Kilometers travelled
First	242	242	06/18/91	06/25/91	7	0
	242	242	06/18/91	06/25/91	7	0
	242	242	06/18/91	07/02/91	14	0
	242	242	06/18/91	06/25/91	7	0
	242	242	06/18/91	06/24/91	6	0
	242	242	06/18/91	07/02/91	14	0
	242	242	06/18/91	07/02/91	14	0
	242	242	06/24/91	07/02/91	8	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	07/03/91	9	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/24/91	06/25/91	1	0
	242	242	06/25/91	07/02/91	7	0
	242	242	06/25/91	07/03/91	8	0
	242	242	06/25/91	07/02/91	7	0
	242	242	06/25/91	07/02/91	7	0
	242	242	06/25/91	07/02/91	7	0
	242	242	06/25/91	07/02/91	7	0
	242	242	06/25/91	07/02/91	7	0

TABLE 3. (CONTINUED)

Recapture event	Release site	Recapture site	Date released	Date recaptured	Time between	interval capture events	Kilometers travelled
Second	235	235	06/04/91	06/12/91		8	0
	242	242	06/18/91	06/25/91		7	0
	242	242	06/18/91	06/25/91		7	0
	242	242	06/18/91	06/25/91		7	0
	242	242	06/18/91	06/25/91		7	0
	242	242	06/06/91	07/02/91		26	0
	242	242	06/18/91	07/02/91		14	0
	242	242	06/18/91	07/03/91		15	0
	242	242	06/25/91	07/03/91		8	0
	242	242	06/24/91	07/03/91		9	0

It took PIT-tagged fall chinook salmon from 7 to 85 days to reach Lower Granite Dam (Figure 12). Sixty-four PIT-tagged fall chinook salmon were detected at Lower Granite Dam between 11 June and 5 September, 1991 (Figure 13). Detection of tagged fall chinook salmon at Lower Granite peaked on 25 July. The detection pattern of tagged fall chinook salmon and the subyearling chinook salmon passage index at Lower Granite as estimated by the SMP (Fish Passage Center 1992) was quite similar (Figure 13).
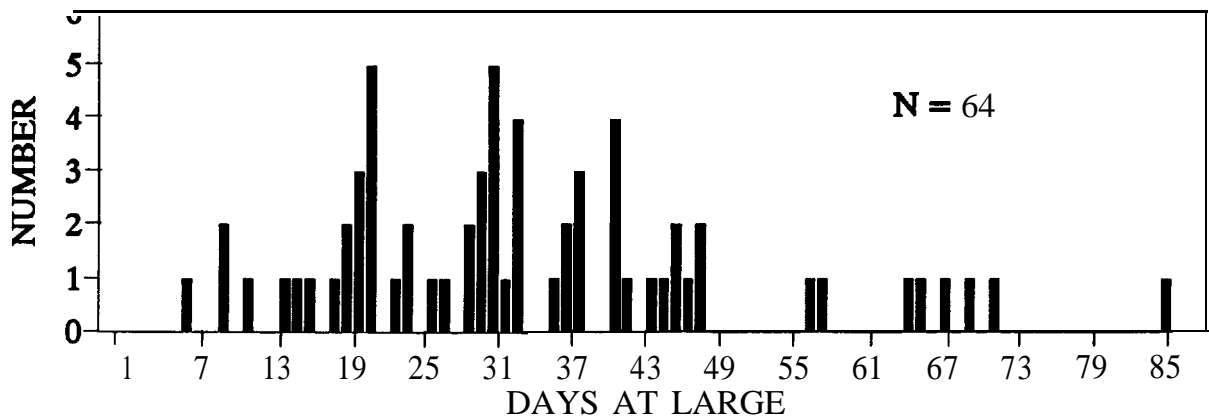
Figure 12. Number of days PIT-tagged Snake River fall chinook salmon juveniles were at large in 1991 before detection at Lower Granite Dam.
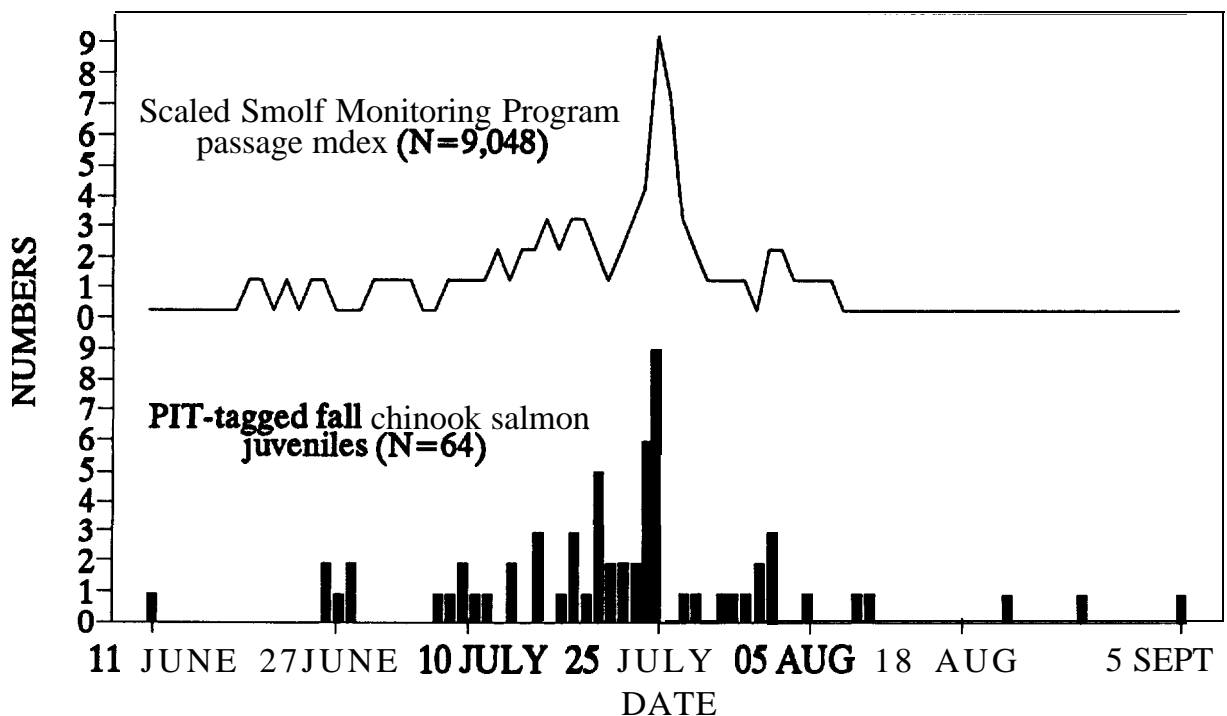
Figure 13. PIT-tag detection numbers for Snake River fall chinook salmon juveniles compared to Smolt Monitoring Program (SMP) subyearling chinook salmon salmon passage indices for the 1991 migration year.

The length-frequency distributions for PIT-tagged fall
chinook salmon were different for each capture event (Figure 14).
Salmon captured by seine then tagged, ranged in size from 55 mm
to 108 mm fork length and averaged 75 $\pm$ 15 mm. Tagged fall
chinook salmon recaptured by seine, ranged in size from 58 mm to
110 mm and averaged 83 $\pm$ 11 mm. Tagged fall chinook salmon
diverted and measured at Lower Granite Dam ranged from 93 mm to
147 mm and averaged 127 $\pm$ 11 mm.
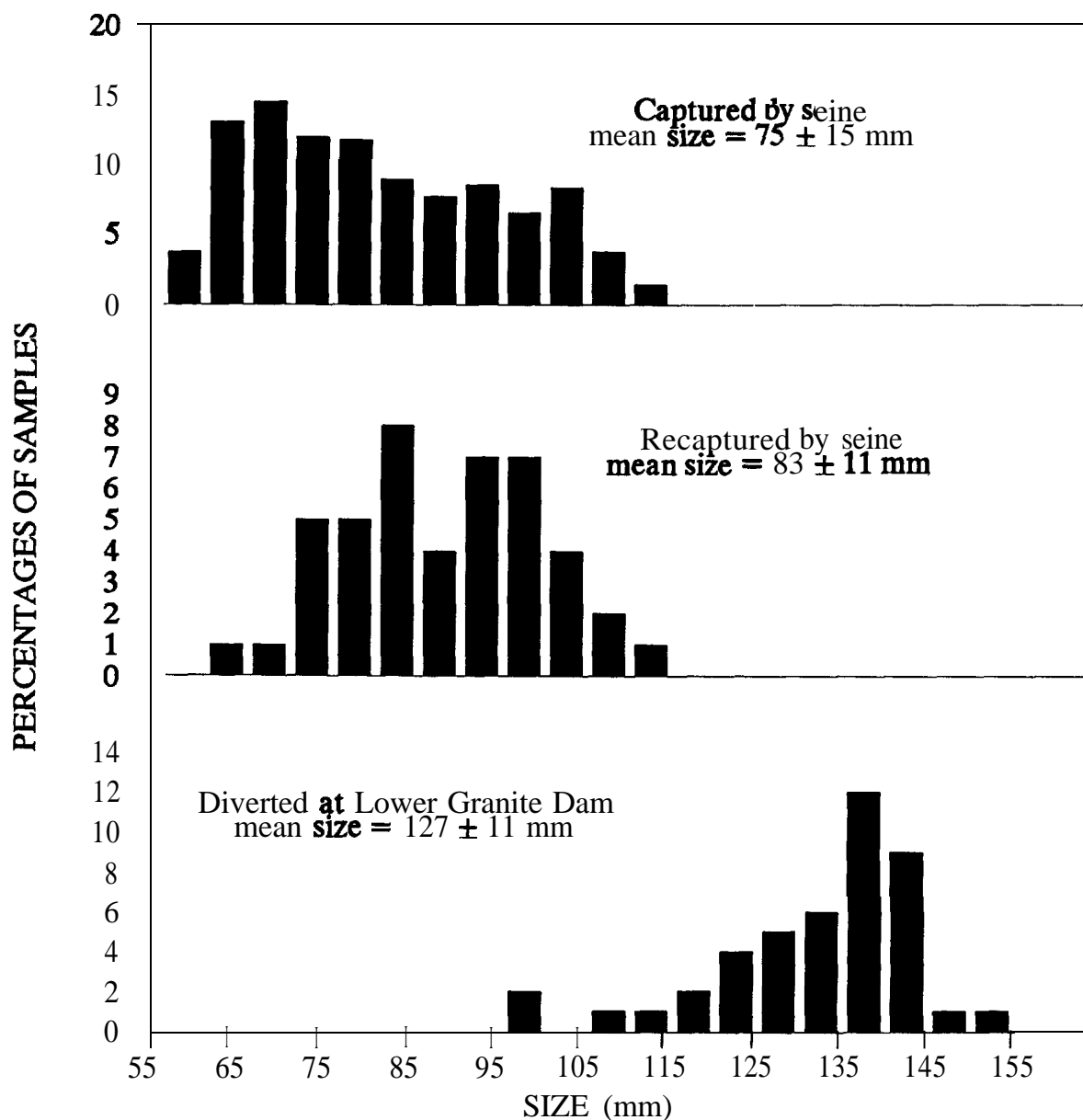
Figure 14. Length frequency distriiutions for Snake River fall chinook salmon
juveniles PIT tagged in 1991, some of which were recaptured by seine, and\or
detected later at Lower Granite Dam.

A Hypothetical Approach for Relating Fall Chinook Salmon Size, Flow, and Water Temperature to Emigration Rate

PIT-tagged fall chinook salmon emigrated to Lower Granite Dam at an average of 2.3 km/d (SD $\pm$ 1.0 km/d; range 0.6-5.1 km/d; Figure 15). Fifty-three percent of the variation in 1991 emigration rate was explained by release size of fall chinook salmon (Figure 16). The resulting relation for emigration rate and release size in 1991 was:

Emigration rate = -15.943 + 4.128 lnRELSZ
Where: RELSZ = salmon size at release.

This suggests that small fall chinook salmon migrated downriver slower than those tagged at larger sizes. However, this relationship was not as clear as it seems because some smaller PIT-tagged fall chinook salmon were recaptured at the original tagging site three weeks later (Table 3; Figure 14). We hypothesized fall chinook salmon grow to a certain size range and change behavior patterns and actively migrate.

The r^2 values from the series of linear regressions by 5 mm size increments produced a pair of bell shaped curves with a maximum r value occurring at 85 mm (Figure 17). From Figure 17 we concluded 85 mm was representative of the minimum emigration size for fall chinook salmon in 1991.

We selected the data set adjusted for the 85 mm minimum emigration size to relate fall chinook salmon emigration rate to the environmental and biological variables of, 1) release temperature, 2) adjusted emigration temperature (emigration temperature), 3) adjusted emigration flow (emigration flow), and 4) release size. We used the 85 mm data set for a forward stepwise multilinear regression (MGLH) that started with a test for relations among the four independent variables. As shown in Table 4, emigration temperature and emigration flow are highly related, 0.915 regression coefficient, as are release temperature and release size, -0.816 regression coefficient. The MGLH model run eliminated emigration temperature and size at release from the analysis because of the above relations, and because they contributed very little to increasing the R^2 value. This seems logical in that flow can have a significant effect on water temperature. Likewise, size at release and water temperature are closely related because both increased with time. It is reasonable that the model removed release size from the analysis because we already standardized this variable by adjusting the data for the 85 mm migration size.
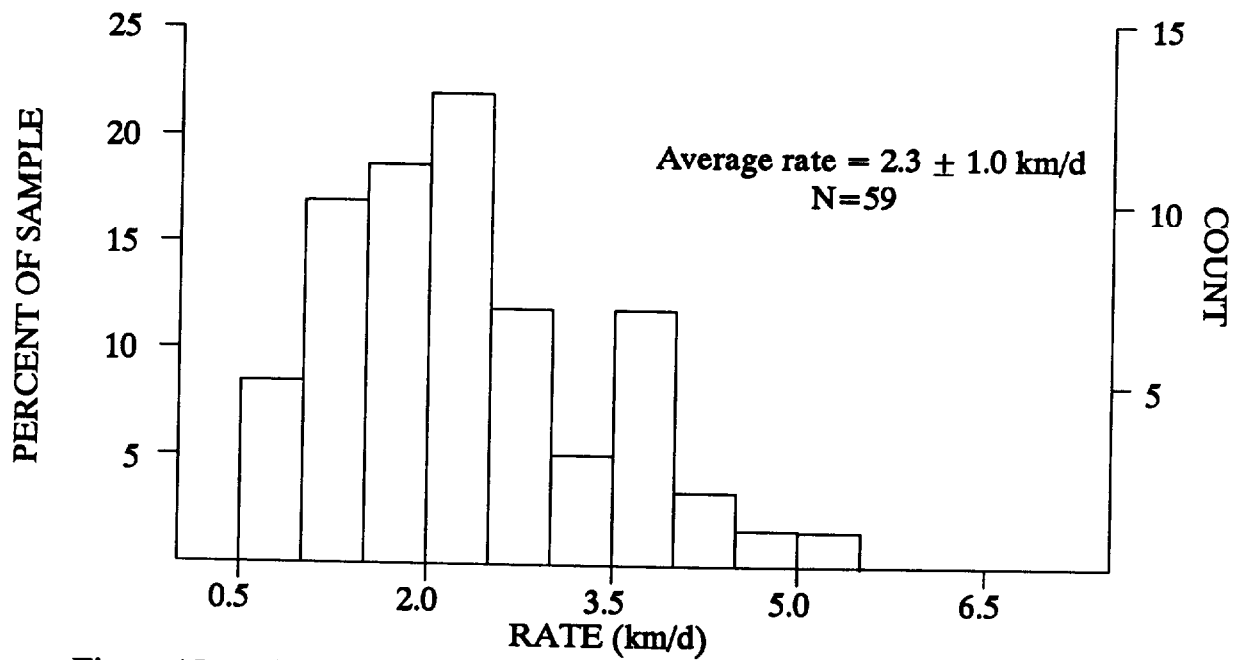
Figure 15. Emigration rate frequency distribution for Snake fall chinook salmon juveniles PIT tagged in 1991. Iterations were made with linear regression to to cull outliers before these data were graphed.

$$Y = -15.943 + \ln X * 4.128$$
$$r^2 = 0.53$$
$$N = 59$$
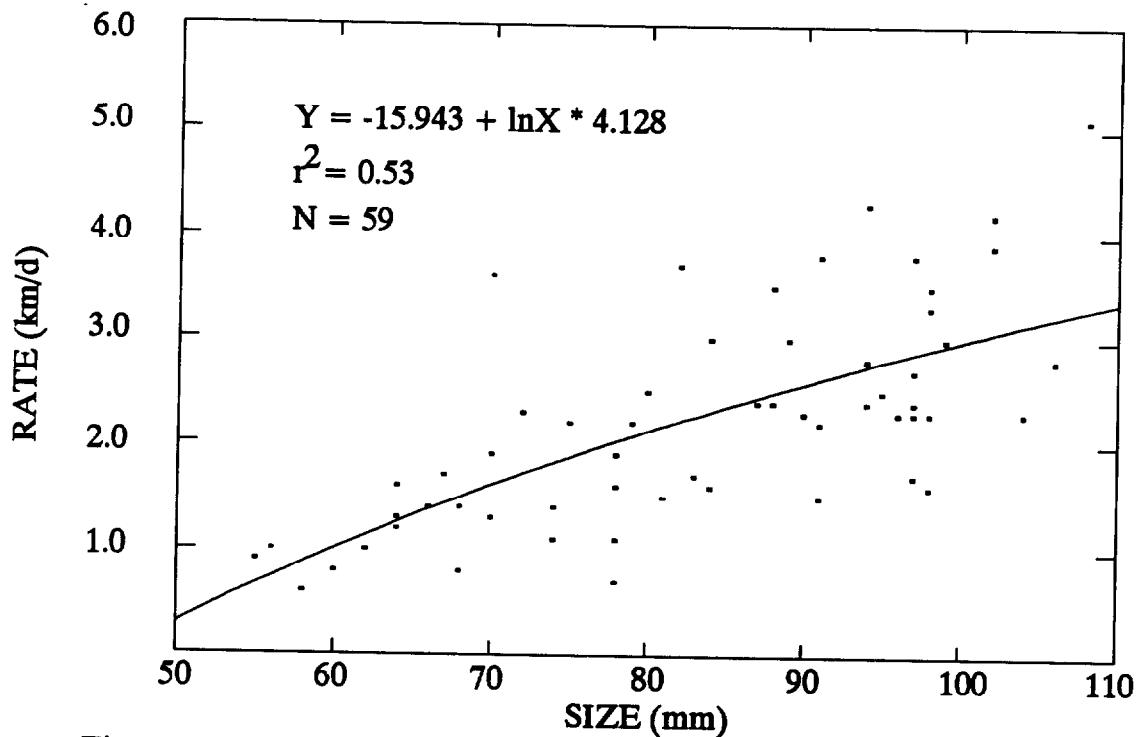
Figure 16. Regression relation between emigration rate and release size for Snake River fall chinook salmon juveniles PIT tagged in 1991. This figure is the last of the iterations refered to in Figure 15.
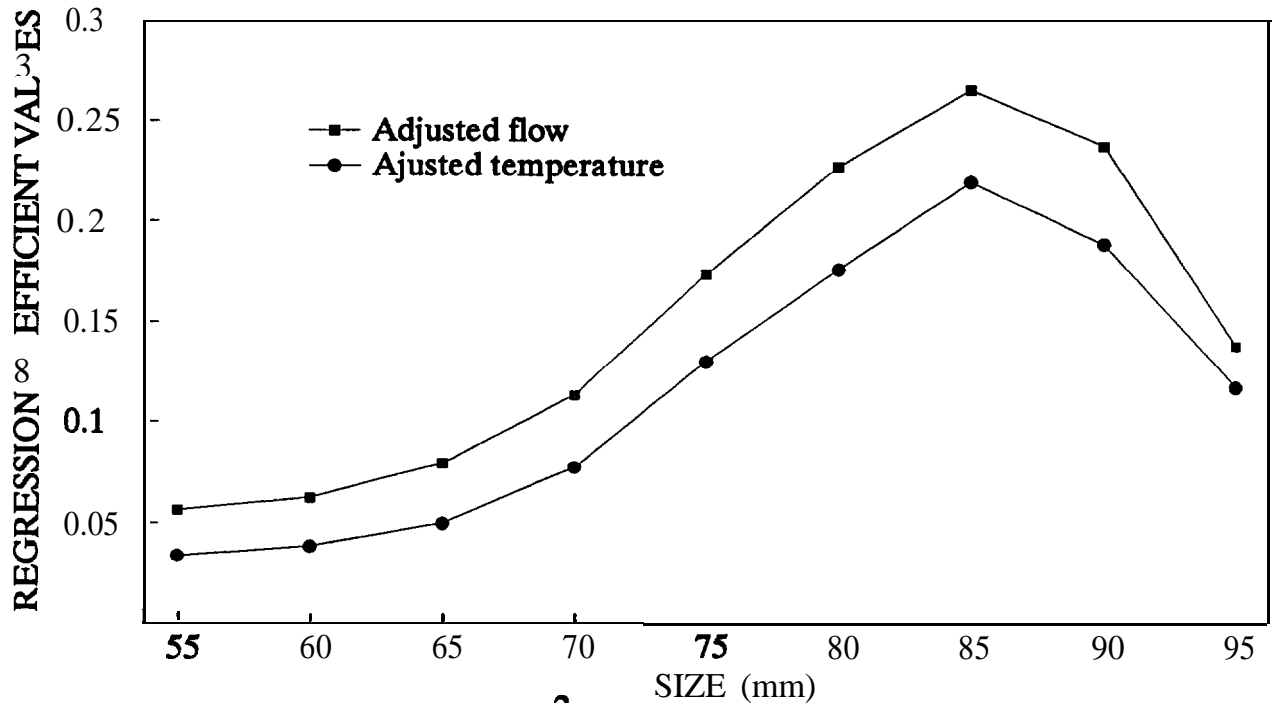
Figure 17. Linear regression r^2 values by 5 mm fall chinook salmon size increments. Data are from fall chinook salmon juveniles PIT tagged in the Snake River and detected at Lower Granite Dam, 1991.

Table 4. Correlation matrix of regression coefficients calculated using adjusted data from 85 mm long Snake River fall chinook salmon juveniles, 1991. Note that these regression coefficients are not r^2 values from linear regression or correlation coefficient r values calculated between independent variables.

	Constant	Release size	Emigration flow	Emigration temperature	Release temperature
constant	1.000				
Release size	-0.1%	1.000			
Emigration flow	-0.939	-0.065	1.000		
Emigration temperature	-0.984	0.198	0.915	1.000	
Release temperature	0.216	-0.816	-0.054	-0.303	1.000

Analysis by MGLH of emigration flow and release water temperature indicates that after fall chinook salmon size is adjusted to a minimum of 85 mm, 57% of the variability in emigration rate is explained by flow during emigration and the water temperature when the fish was originally released (Table 5).

The relation of emigration rate to emigration flow and release temperature for 1991 was:

$$RATE = -18.322 + 2.502 \ \ lnFLOW + 4.304 \ lnRELTEMP$$

Where: RATE = Adjusted emigration rate (km/d);
FLOW = Adjusted emigration flow (KCFS); and
RELTEMP = Release temperature ($^\circ$C).

Furthermore, data in Table 5 show that the response in emigration rate was slightly higher when flow increases (standardized coefficient 0.607), than when temperature increases (standardized coefficient 0.559). This relation predicts that 85 mm fall chinook salmon released in 17 $^\circ$C water at a flow of 70 KCFS would emigrate almost five times faster than 85 mm fish released in 11 $^\circ$C water at a flow of 30 KCFS (Figure 18).

Table 5. SYSTAT multiple regression output (forward stepwise) for relation among adjusted emigration rate (MIGRRATE), adjusted flow (LNFLOW), and release temperature (LNRELT). Data were collected by PIT tagging Snake River fall chinook salmon juveniles, 1991.

DEP VAR:MIGRRATE   N: 59 MULTIPLE R: 0.755   SWARED MULTIPLE R: 0.570
ADJUSTED SQUARED MULTIPLE R:.554   STANDARD ERROR OF ESTIMATE: 0.622

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	-18.322	2.443	0.000	.	-7.499	0.000
LNFLOW	2.502	0.366	0.607	0.973	6.834	0.000
LNRELT	4.304	0.684	0.559	0.973	6.296	0.000

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	D F	MEAN-SQUARE	F-RATIO	P
REGRESSION	28.686	5%	14.343	37.087	0.000
RESIDUAL	21.658		0.387		

RATE= -18.322 + 2.502*lnFLOW + 4.304*lnTEMPERATURE

R^2= 0.57
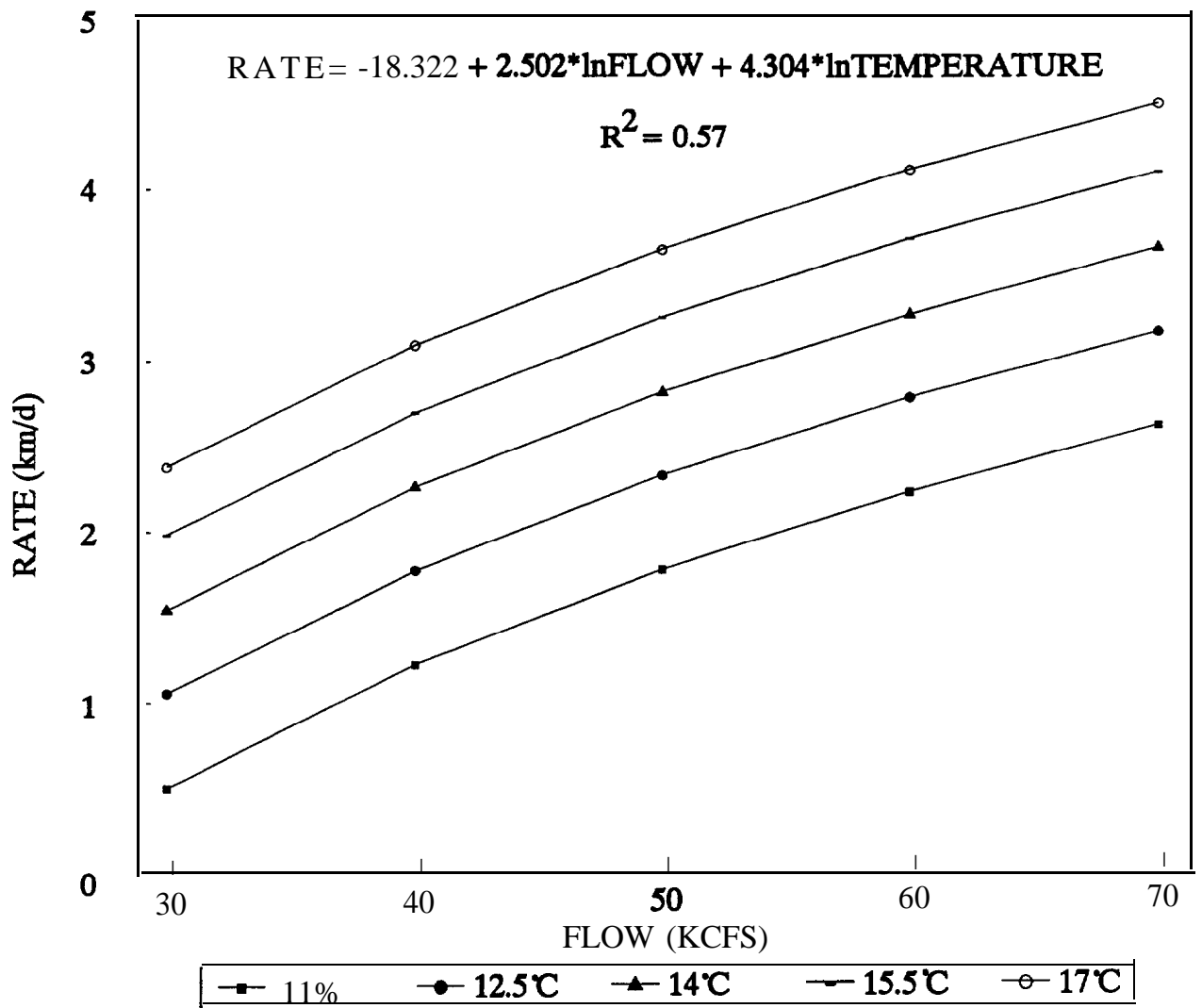
Figure 18. Family of predicted emigration rate, flow, and release water temperature curves for fall chinook salmon juveniles PIT tagged in the Snake Snake River and detected at Lower Granite Dam, 1991.

Discussion

The use of beach seines to sample fall chinook salmon proved effective under the difficult conditions present in the Snake River. Notably, few of the chinook salmon we PIT tagged were subyearling spring/summer chinook salmon. However, chinook salmon tagged at the IDFG smolt trap at Lewiston and collected by SMP personnel at Lower Granite Dam were almost an equal mixture of spring/summer and fall race salmon (L. Blankenship, Washington Department of Fisheries, personal communication). One reason why we tagged mostly fall chinook salmon may relate to juvenile chinook salmon habitat selection. Spring/summer chinook salmon typically do not outmigrate as subyearlings so individuals encountered in the Snake River may have been displaced from their natal tributaries by spring freshets. We captured and tagged a high percentage of natural fall chinook salmon because this race disperses downstream and resides in the low velocity nearshore rearing areas we seined. Our sampling success in 1991 justifies the use of seines in future field seasons.

The results of electrophoresis helped in two very important ways in 1991. First, if we extrapolate the results from the 49 PIT-tagged chinook salmon diverted at Lower Granite Dam, we can say that 94% of the fish we tagged were fall chinook salmon. The size limits coupled with our ability to subjectively judge chinook salmon race proved effective. This approach, however, was not perfect, since 6% of our tagged chinook salmon were of the spring/summer race. Given that these spring/summer chinook salmon were age 0 fish that overlapped in size with fall chinook salmon, it is highly unlikely that we can ever expect a flawless in-season method to judge the race of subyearling fish. The second way electrophoresis facilitated our work was by giving us a means to develop a post-season size limit to separate our seine catch by juvenile chinook salmon race.

Applying the post-season size limit to the fork lengths of the 738 chinook salmon we PIT tagged, separated 650 of the fish as fall chinook salmon. This conservative post-season chinook salmon race separation method improved our confidence when describing fall chinook salmon emergence, rearing, and emigration in 1991. During fall chinook salmon preservation efforts in 1957 IDFG operated Kray-Meekin traps to document the timing of downstream migrants as they passed the uncompleted Hells Canyon impoundment (Bell 1957). Data from this study showed capture of 51 to 85 mm chinook salmon parr peaked in May. In 1991, PIT-tagged fall chinook salmon had a very similar length frequency distribution. In the first few years after 1957, IDFG traps were operated almost continuously to monitor the efficiency of Brownlee Dam fish barriers intended to intercept and bypass migrating salmon entering the reservoir (Bell 1959, 1960, 1961; Graban 1964). This monitoring documented a bi-modal emigration pattern consisting of juvenile fall chinook salmon dispersal

after emergence in April and May and smolt emigration from June
through September. In 1991, PIT-tagged fall chinook salmon
rearing in nearshore areas appears to have begun in May and
extended through mid-July much as salmon rearing did in the late
1950's and early 1960's. The fact some fall chinook salmon
showed high fidelity to nearshore rearing in 1991 was unexpected
and would not have been detectable without the PIT-tag.

Once the fall chinook salmon we PIT tagged in 1991 became
migrants most of them behaved similarly to their untagged
counterparts as evidenced by the similarity between SMP
subyearling chinook salmon passage indices (Fish Passage Center
1992) and our PIT-tagged fall chinook salmon detections at Lower
Granite Dam. Fall chinook salmon arrival at Lower Granite Dam
was a summer event in 1991 as in most years. However,
subyearling chinook salmon numbers at dams during the 1980's
indicated emigration from the free-flowing Snake River and
through Lower Granite Reservoir usually occurs in late June
rather than July as in 1991 (Fish Transport Oversight Team data
summarized by Chapman et al. 1991, Connor et al. 1992).

Fall chinook salmon that we PIT tagged arrived at Lower
Granite Dam at sizes larger (mean length = 127 mm) than observed
in fall chinook salmon emigrating from the mid-Columbia River by
our colleagues (Nelson et al. 1993 in this report). In the mid-
Columbia River component of the study, migrant chinook salmon at
McNary Dam ranged in mean length from 99 mm to 108 mm. The size
difference between Snake River and mid-Columbia River chinook
salmon captured at dams and the offshore movement we observed at
85 mm length suggests that Snake River and mid-Columbia River
fall chinook salmon are probably going through behavioral changes
at the same size, but it may take Snake River salmon longer to
reach the first dam.

Prior to our study, there were no data on the emigration
rate of fall chinook salmon from the free-flowing Snake River to
Lower Granite Dam. With one year of data we learned that
emigration may be affected by a number of factors including fall
chinook salmon size, river flow, and water temperature. The
recapture of PIT-tagged fall chinook salmon in 1991 revealed why
flow had little influence on fall chinook salmon emigration rate
until size was considered in the analysis. The 1991 emigration
rate and water temperature relation analysis eliminated water
temperature during emigration as a variable, yet higher water
temperatures at release were related significantly to higher
emigration rates. In the Columbia River portion of our study,
Nelson et al. (1993 in this report) also found no correlation
with emigration temperature and subyearling chinook salmon
swimming response. Continued field work coupled with ongoing
laboratory study will refine our understanding of the fish size,
emigration rate, river flow, and water temperature relation.

In summary, we seined and PIT tagged 738 chinook salmon juveniles in 1991; 650 of which we analyzed as fall chinook salmon (88%) on the basis of post season race separation. Genetic analysis suggested that 94% of the chinook salmon we PIT tagged and recaptured at Lower Granite Dam were fall chinook salmon. We tagged most of the fall chinook salmon in the Snake River on 25 June at RK 242. About 8 percent (N=53) of all tagged fall chinook salmon were recaptured by seine and all were in good condition. Mean emigration rate from release sites in Hells Canyon to Lower Granite Dam was 2.3 km/d with peak passage in late July. Using an approach of the Fish Passage Center (1992) we estimated that emigration rate was significantly influenced by salmon size, flow, and water temperature at release. It is important to realize that the low population level of Snake River fall chinook salmon dictated that our sample sizes for analyses were small. These preliminary analyses and interpretations Will be refined with the collection of additional data in the future.

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Appendix 5. Summary of the number of subyearling chinook salmon marked with coded wire tags and brands or considered not suitable for marking at McNary Dam during June to August, 1991.

Appendix 6. Data used for fall chinook salmon size versus emigration rate regression analysis.

Appendix 7. Data used for fall chinook salmon emigration rate regression analysis.

APPENDIX 1.   United States Geological Survey Snake River daily average discharge   data from Anatone Gage, Washington, 1967-1992.

Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92
25-Aug	19443	11000	22-Oct	24671	14000	19-Dec	28367	17200	15-Feb	34510	16600	14-Apr	53952	25500
26-Aug	19268	11300	23-Oct	25152	14200	20-Dec	28148	19500	16-Feb	35910	16700	15-Apr	553%	25500
27-Aug	18699	11700	24-Oct	24548	14300	21-Dec	28210	18200	17-Feb	38014	16700	16-Apr	55486	25200
28-Aug	18662	12000	25-Oct	24381	14200	22-Dec	27633	16500	18-Feb	38652	17600	17-Apr	55800	25400
29-Aug	18454	12100	26-Oct	24362	14100	23-Dec	28824	16600	19-Feb	39295	18700	18-Apr	54933	28000
30-Aug	174%	12600	27-Oct	24343	14200	24-Dec	28448	15900	20-Feb	39505	20100	19-Apr	545%	29100
31-Aug	17238	13500	28-Oct	24667	14200	25-Dec	26790	15200	21-Feb	40748	26100	20-Apr	54000	27800
01-Sep	18138	13000	29-Oct	24557	14400	26-Dec	27281	15200	22-Feb	41014	26700	21 -Apr	54071	26700
02-Sep	18619	12800	30-Oct	23748	14200	27-Dec	28257	15400	23-Feb	44233	26600	22-Apr	54752	27700
03-Sep	18210	12700	31-Oct	23952	14000	28-Dec	28557	16600	24-Feb	44257	25300	23-Apr	56000	28900
04-Sep	17985	12800	01-Nov	23205	13900	29-Dec	29271	15800	25-Feb	43452	25500	24-Apr	576%	25600
05-Sep	18320	13800	02-Nov	24138	13900	30-Dec	28648	15000	26-Feb	42386	25200	25-Apr	59224	24300
06-Sep	18108	13500	03-Nov	24705	14100	31-Dec	29114	15500	27-Feb	41952	25900	26-Apr	59057	24000
07-Sep	18710	17400	04-Nov	24271	13900	01-Jan	28971	15200	28-Feb	41729	24800	27-Apr	58800	25800
08-Sep	18990	17300	05-Nov	24714	14000	02-Jan	29024	15900	01-Mar	42029	25500	28-Apr	60790	31800
09-Sep	19317	19600	06-Nov	25229	15200	03-Jan	29976	19900	02-Mar	41000	23900	29-Apr	61271	29100
IO-sep	19754	22200	07-Nov	25090	16100	04-Jan	294%	17100	03-Mar	41095	26100	30-Apr	61043	32300
11-sep	20226	22400	08-Nov	25067	16100	OS-Jan	29124	15900	04-Mar	41090	24100	01-May	60838	40900
12-Sep	20217	22700	09-Nov	25876	15900	06-Jan	30090	15300	05-Mar	40414	24500	02-May	61971	47200
13-Sep	20130	23100	10-Nov	26224	16000	07-Jan	31500	18000	06-Mar	41386	25600	03-May	62676	45000
14-Sep	20481	23300	11-Nov	26671	16100	08-Jan	31129	22200	07-Mar	41852	23600	04-May	64271	44200
15-Sep	20548	23200	12-Nov	27010	16000	W-Jan	30400	21800	08-Mar	42367	23400	05-May	65714	44600
16-Sep	20593	23200	13-Nov	27.395	16300	10-Jan	30238	19800	09-Mar	43148	23700	06-May	66767	42500
17-Sep	21593	23100	14-Nov	26690	16700	11-Jan	304%	18800	10-Mar	43943	23500	07-May	67610	37100
18-Sep	21713	23100	15-Nov	26110	16600	12-Jan	30210	16500	11-Mar	44376	24400	08-May	68048	39700
19-Sep	21899	23200	16-Nov	26167	16100	13-Jan	293%	15900	12-Mar	45276	22600	09-May	68671	40900
PO-sep	21179	16200	17-Nov	264%	15600	14-Jan	29143	17900	13-Mar	45300	22900	IO-May	69510	40000
21-Sep	21043	18300	18-Nov	26371	15300	15-Jan	29681	19600	14-Mar	45771	22000	11-May	69962	36400
22-Sep	21581	16600	19-Nov	26976	15300	16-Jan	31381	18100	15-Mar	46676	20100	12-May	69467	33300
23-Sep	21948	16600	20-Nov	26829	15600	17-Jan	33471	17300	16-Mar	46210	22200			
24-Sep	21767	17600	21-Nov	26338	15800	18-Jan	33038	17300	17-Mar	47076	25300			
25-Sep	21648	16800	22-Nov	25710	15600	19-Jan	34105	16400	18-Mar	47314	23800			
26-Sep	21767	15600	23-Nov	25567	15300	20-Jan	35000	17600	19-Mar	47281	24800			
27-Sep	21714	16800	24-Nov	25257	15000	21-Jan	35414	19600	20-Mar	46405	20200			
28-Sep	21329	15900	25-Nov	25852	14900	22-Jan	35329	18100	21-Mar	45633	19600			
29-Sep	21267	15000	26-Nov	26095	15900	23-Jan	34762	16300	22-Mar	45400	19200			
30-Sep	21629	14400	27-Nov	25948	16700	24-Jan	34619	16700	23-Mar	44852	20400			
01-Oct	21329	15600	28-Nov	25886	17000	25-Jan	35690	16600	24-Mar	45681	22100			
02-Oct	20924	14500	29-Nov	25300	16900	26-Jan	36219	15100	25-Mar	46338	18600			
03-Oct	21110	15100	JO-Nov	25710	16400	27-Jan	36200	15800	26-Mar	46043	18400			
04-Oct	21552	15000	01-Dec	26833	15900	28-Jan	36152	19800	27-Mar	46843	18500			
05-Oct	21614	16100	02-Dec	27662	15500	29-Jan	35671	19900	28-Mar	47471	18600			
06-Oct	21481	15400	03-Dec	28229	15200	30-Jan	34876	17000	29-Mar	47581	18700			
07-Oct	22305	15500	04-Dec	28076	15500	31-Jan	34376	19200	30-Mar	48052	18700			
08-Oct	22900	15900	05-Dec	28571	15700	01-Feb	34219	19100	31-Mar	48657	18700			
09-Oct	22414	16400	06-Dec	28105	15900	02-Feb	33629	19100	01-Apr	49476	10800			
10-Oct	22024	15900	07-Dec	27795	18000	03-Feb	32790	19100	02-Apr	50057	19300			
11-Oct	22005	14700	08-Dec	28600	19500	04-Feb	32505	19100	03-Apr	50543	20100			

Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92	Date	1967-88	1991-92
12-Oct	22548	14500	09-Dec	28762	19000	05-Feb	31748	19100	04-Apr	49433	21200			
13-Oct	22981	14300	10-Dec	28300	18100	06-Feb	31286	19100	05-Apr	49195	22000			
14-Oct	23010	14600	11-Dec	28548	17600	07-Feb	30924	19100	06-Apr	49657	21800			
15-Oct	23495	16400	12-Dec	27957	17000	08-Feb	30743	19100	07-Apr	50500	21100			
16-Oct	23471	15100	13-Dec	28195	16600	09-Feb	31286	19100	08-Apr	50714	20300			
17-Oct	23610	14200	14-Dec	28419	16700	10-Feb	31357	18300	09-Apr	51648	19800			
18-Oct	23390	14800	15-Dec	28505	16100	11-Feb	31771	17600	10-Apr	53186	20600			
19-Oct	23571	14400	16-Dec	28562	17300	12-Feb	32090	17400	11-Apr	54110	22400			
20-Oct	23400	14200	17-Dec	28433	18300	13-Feb	32090	18600	12-Apr	53352	23200			
21-Oct	24000	14200	18-Dec	28890	16500	14-Feb	33519	16800	13-Apr	53824	24000			

APPENDIX 2. United States Geological Survey daily average discharge data from Hells Canyon Dam, Imnaha River, Salmon River, and Grande Ronde River, 1991-1992.

Month	Year	Complex	Imnaha	Salmon	G. Ronde	Anatone Gage
25-Aug	1991	7220	139	3640	541	11000
26-Aug	1991	7550	138	3580	527	11300
27-Aug	1991	8160	137	3530	539	11700
28-Aug	1991	7900	137	3520	561	12000
29-Aug	1991	8220	135	3650	581	12100
30-Aug	1991	9330	130	3630	576	12600
31-Aug	1991	8760	127	3550	567	13500
01-Sep	1991	8950	126	3460	559	13000
02-Sep	1991	8760	126	3400	564	12800
03-Sep	1991	8910	126	3360	573	12700
04-Sep	1991	9810	126	3320	577	12800
05-Sep	1991	9890	124	3290	572	13800
06-Sep	1991	11800	123	3260	566	13500
07-Sep	1991	14000	123	3230	539	17400
08-Sep	1991	14100	124	3190	521	17300
09-Sep	1991	18800	126	3210	530	19600
10-Sep	1991	19200	133	3270	530	22200
11-Sep	1991	19300	136	3330	532	22400
12-Sep	1991	19300	127	3700	524	22700
13-Sep	1991	19300	123	4040	525	23100
14-Sep	1991	19300	122	3970	529	23300
15-Sep	1991	19400	121	3870	525	23200
16-Sep	1991	19400	117	3800	525	23200
17-Sep	1991	19300	115	3760	511	23100
18-Sep	1991	19500	114	3740	491	23100
19-Sep	1991	16200	115	3630	478	23200
20-Sep	1991	14200	113	3610	469	16200
21-Sep	1991	13600	112	3560	462	18300
22-Sep	1991	10900	114	3460	442	16600
23-Sep	1991	15200	115	3330	453	16600
24-Sep	1991	13000	114	3370	453	17600
25-Sep	1991	12800	116	3420	456	16800
26-Sep	1991	12700	115	3400	464	15600
27-Sep	1991	12800	114	3340	479	16800
28-Sep	1991	11400	113	3300	481	15900
29-Sep	1991	10100	114	3290	489	15000
30-Sep	1991	12400	112	3380	490	14400
01-Oct	1991	13350	110	3550	490	15600
02-Oct	1991	14300	109	3510	488	14500
03-Oct	1991	9950	110	3440	485	15100
04-Oct	1991	12500	110	3400	493	15000
05-Oct	1991	11800	110	3380	513	16100
06-Oct	1991	11600	109	3390	524	15400
07-Oct	1991	12200	109	3620	557	15500
08-Oct	1991	11600	109	3440	544	15900
09-Oct	1991	13000	109	3440	543	16400
10-Oct	1991	10600	108	3420	532	15900
11-Oct	1991	10400	107	3420	521	14700
12-Oct	1991	10400	106	3400	518	14500

Month	Year	Complex	Imnaha	Salmon	G. Ronde	Anatone	Gage
13-Oct	1991	10200	106	3390	505	14300	
14-Oct	1991	11600	106	3390	495	14600	
15-Oct	1991	12400	106	3380	506	16400	
16-Oct	1991	10200	108	3390	520	15100	
17-Oct	1991	10200	113	3390	527	14200	
18-Oct	1991	11000	114	3370	529	14800	
19-Oct	1991	10200	114	3390	542	14400	
20-Oct	1991	10100	116	3380	549	14200	
21-Oct	1991	10100	114	3450	555	14200	
22-Oct	1991	9930	115	3540	558	14000	
23-Oct	1991	9970	123	3650	562	14200	
24-Oct	1991	9880	124	3710	586	14300	
25-Oct	1991	9610	127	3780	629	14200	
26-Oct	1991	9500	142	3890	654	14100	
27-Oct	1991	9460	143	4010	634	14200	
28-Oct	1991	9470	128	4180	623	14200	
29-Oct	1991	9480	126	4090	622	14400	
30-Oct	1991	9480	118	3570	618	14200	
31-Oct	1991	9450	117	3730	608	14000	
01-Nov	1991	9420	138	3730	652	13900	
02-Nov	1991	9450	122	3940	662	13900	
03-Nov	1991	9420	106	3810	633	14100	
04-Nov	1991	9420	134	3560	644	13900	
05-Nov	1991	9610	143	3890	872	14000	
06-Nov	1991	9690	171	4790	1310	15200	
07-Nov	1991	9700	153	5220	1130	16100	
08-Nov	1991	9720	142	4990	1090	16100	
09-Nov	1991	9740	160	4950	1050	15900	
10-Nov	1991	9690	151	5290	1020	16000	
11-Nov	1991	9690	140	5270	912	16100	
12-Nov	1991	9730	150	5020	962	16000	
13-Nov	1991	9750	209	5290	1390	16300	
14-Nov	1991	9710	175	5620	1240	16700	
15-Nov	1991	9710	153	5620	1100	16600	
16-Nov	1991	9700	133	4950	1010	16100	
17-Nov	1991	9710	152	4410	1060	15600	
18-Nov	1991	9720	153	4360	1070	15300	
19-Nov	1991	9670	142	4580	1050	15300	
20-Nov	1991	9690	147	4510	1250	15600	
21-Nov	1991	9680	146	4460	1400	15800	
22-Nov	1991	9700	133	4430	1230	15600	
23-Nov	1991	9710	97	4250	1090	15300	
24-Nov	1991	9720	139	3910	1020	15000	
25-Nov	1991	9690	153	3750	1290	14900	
26-Nov	1991	9680	150	4250	2290	15900	
27-Nov	1991	9710	150	4530	2300	16700	
28-Nov	1991	9740	146	4620	2340	17000	
29-Nov	1991	9730	141	4530	2200	16900	
30-Nov	1991	9720	108	4310	1890	16400	
01-Dec	1991	9710	119	4040	1640	15900	

Month	Year	Complex	Imnaha	Salmon	G. Ronde	Anatone	Gage
02-Dec	1991	9740	143	3650	1570	15500	
03-Dec	1991	9700	145	3750	1620	15200	
04-Dec	1991	9670	147	4030	1610	15500	
05-Dec	1991	9660	140	4160	1580	15700	
06-Dec	1991	9690	148	4070	2100	15900	
07-Dec	1991	9720	163	4550	3990	18000	
08-Dec	1991	9710	148	5210	3940	19500	
09-Dec	1991	9710	148	5010	3210	19000	
10-Dec	1991	9690	146	4650		18100	
11-Dec	1991	10100	128	4410		17600	
12-Dec	1991	9720	144	4150		17000	
13-Dec	1991	9750	139	3990		16600	
14-Dec	1991	10200	107	4210		16700	
15-Dec	1991	9690	88	3860		16100	
16-Dec	1991	14500	112	3230		17300	
17-Dec	1991	11200	126	2630		18300	
18-Dec	1991	12700	165	2820		16500	
19-Dec	1991	13300	149	3160		17200	
20-Dec	1991	15200	102	3170		19500	
21-Dec	1991	11900	103	3600		18200	
22-Dec	1991	10200	160	3590		16500	
23-Dec	1991	12200	140	3950		16600	
24-Dec	1991	10300	132	3590		15900	
25-Dec	1991	9970	135	3730		15200	
26-Dec	1991	9990	139	3610		15200	
27-Dec	1991	11300	137	3760		15400	
28-Dec	1991	12000	132	3160		16600	
29-Dec	1991	9960	137	3290		15800	
30-Dec	1991	10800	138	3350		15000	
31-Dec	1991	10400	135	3480		15500	
01-Jan	1992	10000	123	3600		15200	
02-Jan	1992	14000	127	3630		15900	
03-Jan	1992	14000	124	3510		19900	
04-Jan	1992	11900	127	3330		17100	
05-Jan	1992	10700	139	3290		15900	
06-Jan	1992	11600	146	3430		15300	
07-Jan	1992	16400	134	3680		18000	
08-Jan	1992	17000	96	3800		22200	
09-Jan	1992	15300	84	3730		21800	
10-Jan	1992	16300	131	3620		19800	
11-Jan	1992	12600	142	3350		18800	
12-Jan	1992	14000	138	3300		16500	
13-Jan	1992	14900	130	3380		15900	
14-Jan	1992	15500	133	3500		17900	
15-Jan	1992	14700	131	3490		19600	
16-Jan	1992	11800	132	3580	872	18100	
17-Jan	1992	13600	126	3550	868	17300	
18-Jan	1992	11800	98	3470	825	17300	
19-Jan	1992	12100	93	3290	754	16400	
20-Jan	1992	16100	90	3040	746	17600	

Month	Year	Complex	Imaha	Salmon	G. Ronde	Anatone	Gage
21-Jan	1992	15400	100	2770	738	19600	
22-Jan	1992	13000	113	2680	798	18100	
23-Jan	1992	12600	147	2840	917	16300	
24-Jan	1992	12800	147	3100	893	16700	
25-Jan	1992	11000	138	3500	888	16600	
26-Jan	1992	9820	129	3680	879	15100	
27-Jan	1992	13300	130	3640	879	15800	
28-Jan	1992	15500	148	3630	1330	19800	
29-Jan	1992	11600	164	3670	1710	19900	
30-Jan	1992	12000	158	3670	1790	17000	
31-Jan	1992	11200	152	3620	1780	19200	
01-Feb	1992	10200	152	3550	1800	19100	
02-Feb	1992	9960	151	3500	1850	19100	
03-Feb	1992	14000	142	3460	1790	19100	
04-Feb	1992	12500	131	3380	1680	19100	
05-Feb	1992	11500	139	3180	1580	19100	
06-Feb	1992	11900	155	2970	1510	19100	
07-Feb	1992	13200	158	2940	1480	19100	
08-Feb	1992	10400	151	3120	1440	19100	
09-Feb	1992	10200	149	3300	1400	19100	
10-Feb	1992	11500	148	3480	1360	18300	
11-Feb	1992	11100	153	3600	1350	17600	
12-Feb	1992	12300	162	3620	1360	17400	
13-Feb	1992	10800	174	3630	1400	18600	
14-Feb	1992	9960	181	3660	1480	16800	
15-Feb	1992	9880	182	3700	1540	16600	
16-Feb	1992	9860	186	3740	1630	16700	
17-Feb	1992	9900	172	3730	1580	16700	
18-Feb	1992	11900	173	3630		17600	
19-Feb	1992	13000	178	3660		18700	
20-Feb	1992	11600	235	4000	3590	20100	
21-Feb	1992	15100	347	4690	6140	26100	
22-Feb	1992	12000	329	4980	6470	26700	
23-Feb	1992	14200	299	5060	5940	26600	
24-Feb	1992	12400	280	4880	5250	25300	
25-Feb	1992	14400	265	4590	5010	25500	
26-Feb	1992	15100	279	4450	4880	25200	
27-Feb	1992	15000	302	4460	4650	25900	
28-Feb	1992	14000	332	4490	4460	24800	
29-Feb	1992	12500	394	4690	4310	25500	
01-Mar	1992	15600	394	4870	4330	23900	
02-Mar	1992	12500	397	5080	4220	26100	
03-Mar	1992	14300	422	5470	4050	24100	
04-Mar	1992	13100	411	5680	3790	24500	
05-Mar	1992	14500	392	5820	3560	25600	
06-Mar	1992	11800	400	5870	3440	23600	
07-Mar	1992	13300	403	5790	3410	23400	
08-Mar	1992	12200	383	5650	3270	23700	
09-Mar	1992	14600	367	5560	3100	23500	
10-Mar	1992	13500	355	5320	2950	24400	

Month	Year	Complex	Imnaha	Salmon	G. Ronde	Anatone	Gage
11-Mar	1992	13300	354	5210	2840	22600	
12-Mar	1992	14900	371	5270	2800	22900	
13-Mar	1992	10100	396	5500	2840	22000	
14-Mar	1992	9840	422	5830	2920	20100	
15-Mar	1992	14800	440	6160	3020	22200	
16-Mar	1992	12500	436	6550	3060	25300	
17-Mar	1992	14500	397	6670	2950	23800	
18-Mar	1992	12100	367	6370	2770	24800	
19-Mar	1992	10000	349	5980	2600	20200	
20-Mar	1992	9850	340	5710	2470	19600	
21-Mar	1992	9840	333	5520	2370	19200	
22-Mar	1992	13600	330	5390	2290	20400	
23-Mar	1992	11400	330	5290	2230	22100	
24-Mar	1992	9850	328	5260	2180	18600	
25-Mar	1992	9820	339	5280	2170	18400	
26-Mar	1992	9850	347	5380	2180	18500	
27-Mar	1992	9850	337	5600	2140	18600	
28-Mar	1992	9790	322	5710	2060	18700	
29-Mar	1992	9880	319	5750	2010	18700	
30-Mar	1992	9800	329	5830	2010	18700	
31-Mar	1992	9810	357	6110	2050	18800	
01-Apr	1992	9790	389	6610	2140	19300	
02-Apr	1992	9890	436	7420	2290	20100	
03-Apr	1992	9350	498	8660	2390	21200	
04-Apr	1992	8820	467	9580	2340	22000	
05-Apr	1992	8710	426	9310	2230	21800	
06-Apr	1992	8720	390	8640	2130	21100	
07-Apr	1992	8710	372	7960	2050	20300	
08-Apr	1992	8720	370	7670	2160	19800	
09-Apr	1992	8710	393	8210	3170	20600	
10-Apr	1992	8690	380	9530	3500	22400	
11-Apr	1992	8700	389	9760	3480	23200	
12-Apr	1992	8740	462	11000	3750	24000	
13-Apr	1992	8720	486	11700	3830	25500	
14-Apr	1992	8730	467	11600	3690	25500	
15-Apr	1992	8730	462	11400	3620	25200	
16-Apr	1992	8710	560	12100	4040	25400	
17-Apr	1992	8690	578	14000	4720	28000	
18-Apr	1992	8670	515	13600	4680	29100	
19-Apr	1992	8670	483	12700	4450	27800	
20-Apr	1992	8710	492	12400	4180	26700	
21-Apr	1992	11500	477	13100	3880	27700	
22-Apr	1992	9330	439	12700	3560	28900	
23-Apr	1992	8490	410	11900	3280	25600	
24-Apr	1992	8580	391	11300	3060	24300	
25-Apr	1992	9490	402	11400	2980	24000	
26-Apr	1992	12800	433	12600	3030	25800	
27-Apr	1992	11000	459	14300	3070	31800	
28-Apr	1992	8670	520	16700	3220	29100	
29-Apr	1992	8520	615	20400	3760	32300	

Month	Year	Complex	Imaha	Salmon	G. Ronde	Anatone	Gage
30-Apr	1992	18300	585	22400	3600	40900	
01 -May	1992	20100	523	20900	3200	47200	
02-May	1992	20100	505	19500	2980	45000	
03-May	1992	20200	521	19300	2910	44200	
04-May	1992	20200	565	20000	2970	44600	
05-May	1992	11300	623	21800	3110	42500	
06-May	1992	8600	682	24100	3310	37100	
07-May	1992	8530	734	25700	3690	39700	
08-May	1992	8490	671	26700	3410	40900	
09-May	1992	8530	586	24900	2950	40000	
10-May	1992	8570	542	22200	2650	36400	
11-May	1992	8590	499	20000	2370	33300	
12-May	1992	8590	458	18000	2160	30900	

APPENDIX 3. United States Geological Survey Snake River daily average water temperature data from Anatone Gage, Washington, 1975-1982.

Month	°C	Month	°C	Month	°C	Month	°C	Month	°C
25-Aug	20.8	17-Oct	14.5	09-Dec	5.7	31-Jan	2.4	24-Mar	7.5
26-Aug	20.6	18-Oct	14.3	10-Dec	5.7	01-Feb	2.3	25-Mar	7.6
27-Aug	20.3	19-Oct	13.9	11-Dec	5.6	02-Feb	2.4	26-Mar	7.8
28-Aug	20.2	20-Oct	13.7	12-Dec	5.5	03-Feb	2.4	27-Mar	7.8
29-Aug	20.3	21-Oct	13.5	13-Dec	5.3	04-Feb	2.2	28-Mar	7.5
30-Aug	20.1	22-Oct	13.2	14-Dec	5.4	05-Feb	2.2	29-Mar	7.4
31-Aug	20.1	23-Oct	13.1	15-Dec	5.6	06-Feb	2.2	30-Mar	7.5
01-Sep	20.7	24-Oct	12.9	16-Dec	5.4	07-Feb	2.3	31-Mar	7
02-Sep	20.8	25-Oct	12.7	17-Dec	5.1	08-Feb	2.3	01-Apr	7.6
03-Sep	21		12.5	18-Dec	5	09-Feb	2.4	02-Apr	7.7
04-Sep	21.1	27-Oct	12.3	19-Dec	4.9	10-Feb	2.4	03-Apr	7.9
05-Sep	21.2	28-Oct	12.2	20-Dec	4.8	11-Feb	2.5	04-Apr	8.4
06-Sep	21	29-Oct	12.3	21-Dec	4.8	12-Feb	2.5	05-Apr	8.6
07-Sep	20.7	30-Oct	12.1	22-Dec	4.8	13-Feb	2.6	06-Apr	8.6
08-Sep	20.3	31-Oct	11.7	23-Dec	4.6	14-Feb	3	07-Apr	8.5
09-Sep	20.2	01-Nov	11.5	24-Dec	4.5	15-Feb	3.3	08-Apr	8.7
10-Sep	20.3	02-Nov	11.4	25-Dec	4.5	16-Feb	3.4	09-Apr	8.8
11-Sep	20.2	03-Nov	11.4	26-Dec	4.5	17-Feb	3.7	10-Apr	8.9
12-Sep	20	04-Nov	11.4	27-Dec	4.6	18-Feb	3.9	11-Apr	9.2
13-Sep	20	05-Nov	11.1	28-Dec	4.5	19-Feb	4.3	12-Apr	9.3
14-Sep	20	06-Nov	11.1	29-Dec	3.9	20-Feb	4.5	13-Apr	9.3
15-Sep	20.1	07-Nov	10.9	30-Dec	3.9	21-Feb	4.4	14-Apr	9.5
16-Sep	19.9	08-Nov	10.7	31-Dec	4	22-Feb	4.5	15-Apr	9.8
17-Sep	19.7	09-Nov	10.4	01-Jan	3.9	23-Feb	4.2	16-Apr	10
18-Sep	19.7	10-Nov	10.2	02-Jan	3.8	24-Feb	4.1	17-Apr	9.8
19-Sep	19.7	11-Nov	9.9	03-Jan	3.8	25-Feb	4.4	18-Apr	10.1
20-Sep	19.7	12-Nov	9.8	04-Jan	3.7	26-Feb		19-Apr	10.4
21-Sep	19.5	13-Nov	9.7	OS-Jan	3.5	27-Feb	4.6	20-Apr	10.3
22-Sep	19.4	14-Nov	9.1	06-Jan	3.1	28-Feb	4.6	21-Apr	10.6
23-Sep	19.3	15-Nov	9	07-Jan	3.1	29-Feb	4.6	22-Apr	10.9
24-Sep	19.2	16-Nov	8.6	08-Jan	3	01-Mar	4.6	23-Apr	11.3
25-Sep	19.3	17-Nov	8.9	09-Jan	2.7	02-Mar	4.7	24-Apr	11.2
26-Sep	19.5	18-Nov	8.6	10-Jan	2.6	03-Mar	4.8	25-Apr	11.1

Month	°C	Month	°C	Month	°C	Month	°C	Month	°C
27-Sep	19.5	19-Nov	8.3	11-Jan	2.7	04-Mar	4.8	26-Apr	11.2
28-Sep	19.4	20-Nov	7.9	12-Jan	2.8	05-Mar	5	27-Apr	11.2
29-Sep	19.4	21-Nov	7.6	13-Jan	2.7	06-Mar	5.4	28-Apr	11.2
30-Sep	19.1	22-Nov	7.8	14-Jan	2.8	07-Mar	5.5	29-Apr	11.3
01-Oct	17.1	23-Nov	7.6	15-Jan	2.9	08-Mar	5.6	30-Apr	11.7
02-Oct	16.9	24-Nov	7.5	16-Jan	2.9	09-Mar	5.8	01-May	11.8
03-Oct	16.6	25-Nov	7.2	17-Jan	3	10-Mar	5.9	02-May	11.9
04-Oct	16.1	26-Nov	7.2	18-Jan	3.1	11-Mar	5.8	03-May	11.2
05-Oct	16	27-Nov	7.1	19-Jan	3	12-Mar	5.9	04-May	10.8
06-Oct	16	28-Nov	7.1	20-Jan	3	13-Mar	5.9	05-May	10.7
07-Oct	16.2	29-Nov	7	21-Jan	3	14-Mar	6	06-May	10.6
08-Oct	16	30-Nov	6.7	22-Jan	2.9	15-Mar	6	07-May	10.8
09-Oct	15.8	01-Dec	6.5	23-Jan	2.8	16-Mar	6	08-May	11.1
10-Oct	15.5	02-Dec	6.5	24-Jan	2.8	17-Mar	6.3	09-May	11.2
11-Oct	15.4	03-Dec	6.3	25-Jan	2.9	18-Mar	6.4	10-May	11.5
12-Oct	15.3	04-Dec	6.5	26-Jan	2.6	19-Mar	6.6	11-May	11.9
13-Oct	15.2	05-Dec	6.2	27-Jan	2.4	20-Mar	6.7	12-May	12.4
14-Oct	15	06-Dec	6	28-Jan	2.3	21-Mar	7.3		
15-Oct	14.9	07-Dec	6.1	29-Jan	2.5	22-Mar	7.4		
16-Oct	14.8	08-Dec	5.8	30-Jan	2.5	23-Mar	7.4		

APPENDIX 4.   Average daily Snake River water and Hells Canyon air temperatures
by RK collected by thermograph for regression analysis, August 1991 to May 1992.

Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR]	AIR-14	AIR-21	AIR_30
25-Aug	21.8	21.4	20.9	20.7	20.6	20.4	19.8	22.3	21.7	27.7	28.9	26.4	30.6	26.4
26-Aug	21	21	20.7	20.5	20.5	20.5	19.2	21.7	20.7	26.1	31.1	26.6	29.1	26.8
27-Aug	20.8	20.7	20.7	20.6	20.7	20.6	19.0	21.1	20.3	27.4	30.7	28.5	29.7	27.9
28-Aug	20.8	20.6	20.8	20.6	20.6	20.8	18.4	20.6	20.2	24.9	30.7	28.9	30.5	29.4
29-Aug	20.9	20.8	20.8	20.7	21	20.9	19.5	21	21	27.2	29.6	29.1	30.2	31.1
30-Aug	21.3	21.2	21.5	21.3	21.2	20.8	19.8	20.9	21.9	28.0	28.8	29.0	30.2	29.0
31-Aug	21.6	21.4	21.5	21.3	21.2	20.5	20.2	21.2	22.2	28.8	28.4	28.4	27.1	30.7
01-Sep	21.4	21.2	21.2	21	20.8	20.4	19.8	21.1	21.5	26.6	27.7	28.9	26.4	28.8
02-Sep	20.7	20.6	20.7	20.5	20.5	20.5	18.5	20.5	19.7	24.6	26.1	31.1	26.6	28.3
03-Sep	20.6	20.4	20.5	20.4	20.5	20.6	18.3	20.4	19.8	26.0	27.4	30.7	28.5	30.2
04-Sep	20.6	20.5	20.7	20.6	20.7	20.8	18.5	20.2	19.9	27.3	24.9	30.7	28.9	30.6
05-Sep	20.8	20.7	21.1	20.9	21	20.9	19.0	20.2	20.1	27.6	27.2	29.6	29.1	29.1
06-Sep	21.1	21	21.3	21.1	21.1	20.9	19.5	20.5	20.6	27.9	28.0	28.8	29.0	29.7
07-Sep	21.3	21.2	21.4	21.3	21.3	20.9	20.3	20.7	21.2	27.7	28.8	28.4	28.4	30.5
08-Sep	21.1	21	21.2	21	20.9	20.9	19.1	20.5	19.9	23.2	26.6	27.7	28.9	30.2
09-Sep	20.5	20.5	20.8	20.6	20.8	21.0	17.3	20	18.5	20.9	24.6	26.1	31.1	30.2
IO-sep	20.6	20.6	20.9	20.8	21	21.0	17.3	19.6	18.1	20.7	26.0	27.4	30.7	27.1
11-Sep	20.6	20.6	21.1	20.9	21	20.9	17.2	19	18	21.4	27.3	24.9	30.7	26.4
12-Sep	20.8	20.7	21.1	21	21	20.9	17.7	19	18.5	23.3	27.6	27.2	29.6	26.6
13-Sep	20.6	20.6	21	20.8	20.8	20.8	16.8	18.9	18	22.5	27.9	28.0	28.8	28.5
14-Sep	20	20.1	20.6	20.5	20.7	20.7	15.6	18.2	16.5	19.8	27.7	28.8	28.4	28.9
15-Sep	20	20	20.6	20.4	20.5	20.6	15.4	17.6	16.5	20.0	23.2	26.6	27.7	29.1
16-Sep	20	20	20.7	20.6	20.7	20.8	15.4	17.3	16.8	22.3	20.9	24.6	26.1	29.0
17-Sep	20.1	20.2	20.8	20.7	20.8	20.8	16.0	17.2	17.3	23.9	20.7	26.0	27.4	28.4
18-Sep	20.2	20.2	20.9	20.7	20.8	20.8	16.4	17.1	17.5	22.6	21.4	27.3	24.9	28.9
19-Sep	20.2	20.2	20.8	20.7	20.8	20.6	16.3	17	17.7	22.6	23.3	27.6	27.2	31.1
20-Sep	20	19.9	20.8	20.6	20.6	20.6	16.4	16.8	18.1	23.9	22.5	27.9	28.0	30.7
21-Sep	19.5	19.5	20.3	20.1	20.2	20.5	14.6	16.3	16.3	18.6	19.8	27.7	28.8	30.7
22-Sep	18.8	18.9	19.8	19.7	19.9	20.3	12.9	15.6	14.3	17.8	20.0	23.2	26.6	29.6
23-Sep	18.5	18.6	19.7	19.7	20	20.2	13.0	15.3	14.2	20.0	22.3	20.9	24.6	28.8
24-Sep	19	19	20	19.9	20	20.0	14.0	15.2	14.9	20.9	23.9	20.7	26.0	28.4
25-Sep	19.1	19.1	20	20	20	19.9	15.0	15.4	16	20.7	22.6	21.4	27.3	27.7
26-Sep	19.3	19.1	20.1	20	20	19.9	15.9	15.8	18	21.5	22.6	23.3	27.6	26.1
27-Sep	19.6	19.2	20.2	20	20	19.9	16.3	15.8	17.4	23.3	23.9	22.5	27.9	27.4
28-Sep	19.3	19.2	20.2	20	19.9	19.8	16.6	15.8	17.3	21.3	18.6	19.8	27.7	24.9
29-Sep	19.2	19	20	19.8	19.9	19.8	16.7	15.8	17.3	20.8	17.8	20.0	23.2	27.2
30-Sep	19.1	19	20	19.9	19.9	19.7	16.3	15.8	17.4	22.2	20.0	22.3	20.9	28.0
01-Oct	19.1	19.1	19.9	19.7	19.8	19.7	16.2	16	16.9	23.2	20.9	23.9	20.7	28.8
02-Oct	18.9	18.9	19.7	19.6	19.7	19.6	15.7	15.8	16	21.9	20.7	22.6	21.4	26.6
03-Oct	18.6	18.5	19.3	19.2	19.2	19.4	13.5	15.5	14.7	18.6	21.5	22.6	23.3	24.6
04-Oct	17.5	17.6	18.6	18.5	18.9	19.3	11.4	14.8	12.7	16.6	23.3	23.9	22.5	26.0
05-Oct	17.4	17.5	18.6	18.5	18.8	19.1	10.6	14.1	11.8	16.9	21.3	18.6	19.8	27.3
06-Oct	17.2	17.4	18.6	18.5	18.7	18.9	10.7	13.5	11.5	18.9	20.8	17.8	20.0	27.6
07-Oct	17.1	17.2	18.5	18.4	18.7	18.7	11.5	13.4	11.8	18.1	22.2	20.0	22.3	27.9

Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR-7	AIR-14	AIR-21	AIR_30
08-Oct	17.2	17.3	18.5	18.4	18.4	18.4	12.0	13.2	12	18.7	23.2	20.9	23.9	27.7
09-Oct	17	17	18.2	18.1	18.2	18.3	11.9	12.9	12	19.0	21.9	20.7	22.6	23.2
10-Oct	16.9	16.9	18.2	18	18.2	18.2	11.9	12.5	12.1	18.1	18.6	21.5	22.6	20.9
11-Oct	16.7	16.7	18.1	18	18.1	18.1	12.2	12.3	12.4	20.3	16.6	23.3	23.9	20.7
12-Oct	16.6	16.5	18	17.9	18	18.0	12.7	12.2	12.7	20.7	16.9	21.3	18.6	21.4
13-Oct	16.4	16.4	17.9	17.7	17.9	18.0	12.3	12.3	12.5	19.3	18.9	20.8	17.8	23.3
14-Oct	16.2	16.2	17.6	17.5	17.8	17.9	11.3	12.1	12	17.1	18.1	22.2	20.0	22.5
15-Oct	16.3	16.4	17.8	17.7	17.8	17.9	11.4	12	12.1	19.6	18.7	23.2	20.9	19.8
16-Oct	16.4	16.3	17.7	17.6	17.7	17.8	11.7	11.9	11.9	19.1	19.0	21.9	20.7	20.0
17-Oct	15.7	15.7	17.1	17	17.3	17.7	10.7	11.8	11.2	14.1	18.1	18.6	21.5	22.3
18-Oct	15	15.2	16.6	16.6	17	17.5	8.4	11.2	9	12.4	20.3	16.6	23.3	23.9
19-Oct	15	15.2	16.7	16.7	17	17.3	8.9	10.9	9.5	14.7	20.7	16.9	21.3	22.6
20-Oct	15	15.1	16.7	16.6	16.9	17.1	9.2	10.4	9.4	14.4	19.3	18.9	20.8	22.6
21-Oct	14.9	15	16.8	16.6	16.8	17.0	10.5	10.5	10.1	16.6	17.1	18.1	22.2	23.9
22-Oct	14.7	14.7	16.3	16.2	16.4	16.7	9.2	10.4	9:s	11.3	19.6	18.7	23.2	18.6
23-Oct	14.2	14.3	15.9	15.9	16.2	16.5	8.4	10.2	8.7	9.0	19.1	19.0	21.9	17.8
24-Oct	13.8	14	15.7	15.6	15.8	16.3	7.7	9.7	8.4	8.9	14.1	18.1	18.6	20.0
25-Oct	13.5	13.6	15.3	15.3	15.7	16.0	8.0	9.3	8.1	9.1	12.4	20.3	16.6	20.9
26-Oct	13.2	13.4	15.3	15.3	15.5	15.8	8.2		8.2	9:o	14.7	20.7	16.9	20.7
27-Oct	12.9	13.1	15	15	15.3	15.7	7.3	8.3	7.6	7.7	14.4	19.3	18.9	21.5
28-Oct	12.4	12.5	14.5	14.5	14.9	15.5	5.7	8.2	6.5	6.2	16.6	17.1	18.1	23.3
29-Oct	11.8	12	14.1	14	14.5	15.2	4.7	7.4	5.2	4.5	11.3	19.6	18.7	21.3
30-Oct	11.2	11.5	13.6	13.6	14.1	14.9	3.9	6.4	4.3	4.9	9.0	19.1	19.0	20.8
31-Oct	11	11.4	13.7	13.6	14	14.6	4.2	6.1	3.7	4.4	8.9	14.1	18.1	22.2
01-Nov	11	11.4	13.5	13.5	13.9	14.3	4.5	6.1	3.7	4.7	9.1	12.4	20.3	23.2
02-Nov	10.6	10.8	13	13	13.3	14.0	2.9	5.2	2.6	2.8	9.0	14.7	20.7	21.9
03-Nov	9.9	10.3	12.7	12.7	13.1	13.7	2.3	4.3	2.2	4.8	7.7	14.4	19.3	18.6
04-Nov	10	10.3	12.6	12.6	12.8	13.4	4.1	4.1	3.4	6.3	6.2	16.6	17.1	16.6
05-Nov	10.2	10.3	12.6	12.5	12.8	13.1	6.1	4	5.1	6.7	4.5	11.3	19.6	16.9
06-Nov	10.1	10.2	12.7	12.6	12.7	12.8	7.5	4.2	5.9	8.3	4.9	9.0	19.1	18.9
07-Nov	9.8	9.9	12.5	12.4	12.6	12.6	6.0	4.1	5.9	9.4	4.4	8.9	14.1	18.1
08-Nov	9.4	9.5	12.4	12.3	12.6	12.5	6.5	3.4	6.3	11.9	4.7	9.1	12.4	18.7
09-Nov	9.7	9.8	12.6	12.5	12.5	12.3	9.2	4.2	6.9	10.1	2.8	9.0	14.7	19.0
10-Nov	10	10	12.4	12.2	12.2	12.2	8.5	5	7.3	9.9	4.8	7.7	14.4	18.1
11-Nov	9.8	9.7	12.1	12	12.1	12.1	7.3	5.2	6.8	10.7	6.3	6.2	16.6	20.3
12-Nov	9.9	9.9	12	11.9	12.1	12.1	8.8	6	7.4	10.6	6.7	4.5	11.3	20.7
13-Nov	10.1	10.2	12	11.9	12	11.9	8.4	6.8	7.6	9.7	8.3	4.9	9.0	19.3
14-Nov	9.8	9.9	11.7	11.6	11.7	11.8	6.7	6.5	6.8	8.3	9.4	4.4	8.9	17.1
15-Nov	9.3	9.5	11.3	11.2	11.4	11.7	5.3	6.2	5.7	6.6	11.9	4.7	9.1	19.6
16-Nov	8.9	9.1	11	10.9	11.2	11.5	3.8	5.6	4.3	7.5	10.1	2.8	9.0	19.1
17-Nov	9	9.2	11.1	11	11.2	11.4	6.4	5.4	4.5	8.0	9.9	4.8	7.7	14.1
18-Nov	9.1	9.4	11.1	11.1	11.1	11.1	5.9	5.8	4.6	6.8	10.7	6.3	6.2	12.4
19-Nov	9.1	9.3	10.9	10.8	10.8	10.9	5.1	5.5	5	7.4	10.6	6.7	4.5	14.7
20-Nov	9	8.9	10.8	10.6	10.7	10.7	6.4	5.1	5.8	7.5	9.7	8.3	4.9	14.4
21-Nov	8.6	8.8	10.5	10.4	10.4	10.4	5.6	4.9	5.5	5:s	8.3	9.4	4.4	16.6
22-Nov	8.3	8.4	10.1	9.9	10	10.2	4.0	4.6	4.4	4.3	6.6	11.9	4.7	11.3
23-Nov	7.7	7.9	9.7	9.5	9.7	10.0	2.4	4.1	3.2	4.4	7.5	10.1	2.8	9.0

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Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR_7	AIR_14	AIR_21	AIR_30
24-Nov	7.6	7.8	9.5	9.4	9.7	9.9	3.5	4.1	3.5	4.2	8.0	9.9	4.8	8.9
25-Nov	7.7	7.9	9.6	9.5	9.6	9.8	4.5	4.1	4	5.2	6.8	10.7	6.3	9.1
26-Nov	7.5	7.9	9.6	9.5	9.5	9.5	5.1	4.2	4.1	4.9	7.4	10.6	6.7	9.0
27-Nov	7.5	7.8	9.4	9.3	9.3	9.2	4.9	4.2	4.4	4.4	7.5	9.7	8.3	7.7
28-Nov	7.1	7.4	9.1	9	9	9.1	4.2	3.8	3.7	4.7	5.5	8.3	9.4	6.2
29-Nov	6.7	7	8.8	8.6	8.8	9.0	3.7	3.5	.4	3.7	4.3	6.6	1.9	4.5
30-Nov	6.3	6.6	8.4	8.2	8.5	8.9	2.1	2.9	2.7	1.1	4.4	7.5	0.1	4.9
01-Dec	6.2	6.5	8.4	8.3	8.4	8.7	2.1	2.6	2.4	2.0	4.2	8.0	9.9	4.4
02-Dec	6.4	6.6	8.2	8.1	8.3	8.5	3.4	2.8	3.2	2.8	5.2	6.8	0.7	4.7
03-Dec	6.6	6.6	8.4	8.3	8.4	8.4	4.5	3.1	4.2	5.6	4.9	7.4	0.6	2.8
04-Dec	6.8	6.9	8.4	8.1	8.3	8.4	5.1	3.1	4.8	7.3	4.4	7.5	9.7	4.8
05-Dec	6.7	6.7	8.3	8.1	8.1	8.1	4.6	3.3	4.9	6.9	4.7	5.5	8.3	6.3
06-Dec	6.8	6.7	8.4	8.1	8.1	7.8	6.3	3.2	5.2	7.2	3.7	4.3	6.6	6.7
07-Dec	6.5	6.7	8.1	7.9	7.9	7.8	5.9	3.2	5.1	5.9	1.1	4.4	7.5	8.3
08-Dec	6.4	6.3	7.8	7.7	7.6	7.6	4.9	3.2	5.3	5.2	2.0	4.2	8.0	9.4
09-Dec	5.6	5.9	7.7	7.4	7.5	7.6	4.8	2.8	5	7.4	2.8	5.2	6.8	11.9
10-Dec	5.7	5.9	7.6	7.4	7.6	7.6	4.3	2.9	4.1	4.7	5.6	4.9	7.4	10.1
11-Dec	7	6	7.4	7.2	7.3	7.5	3.4	3.1	3.7	4.8	7.3	4.4	7.5	9.9
12-Dec	6	6	7.4	7.1	7.3	7.3	4.2	3	4.2	4.7	6.9	4.7	5.5	0.7
13-Dec	5.6	5.8	7.1	7	7.1	7.1	3.3	3	3.5	4.4	7.2	3.7	4.3	0.6
14-Dec	5.3	5.5	6.8	6.7	6.8	7.1	1.6	2.6	2.3	3.2	5.9	1.1	4.4	9.7
15-Dec	4.8	5.1	6.7	6.4	6.7	7.0	0.4	1.9	1.1	3.0	5.2	2.0	4.2	8.3
16-Dec	4.6	5	6.5	6.4	6.7	6.8	0.4	1.3	0.9	2.6	7.4	2.8	5.2	6.6
17-Dec	5	5.3	6.5	6.4	6.6	6.7	0.1	0.9	0.6	3.7	4.7	5.6	4.9	7.5
18-Dec	4.9	5.2	6.4	6.3	6.5	6.5	0.9	0.7	1.1	4.2	4.8	7.3	4.4	8.0
19-Dec	5.2	5.4	6.7	6.4	6.5	6.4	2.5	0.9	1.8	4.0	4.7	6.9	4.7	6.8
20-Dec	5	5.2	6.3	6.1	6.3	6.4	0.8	0.8	1.2	1.9	4.4	7.2	3.7	7.4
21-Dec	4.9	4.9	6.1	6	6	6.3	0.6	0.7	1.3	2.8	3.2	5.9	1.1	7.5
22-Dec	4.8	4.8	6.3	6	6.2	6.2	2.5	0.9	1.8	4.1	3.0	5.2	2.0	5.5
23-Dec	4.6	4.7	6.6	5.9	6	6.2	1.2	0.9	2.1	3.0	2.6	7.4	2.8	4.3
24-Dec	4.7	4.7	6	5.9	5.9	6.1	0.6	0.9	1.9	2.1	3.7	4.7	5.6	4.4
25-Dec	4.4	4.4	6	5.8	5.9	6.0	0.6	0.8	1.5	3.5	4.2	4.8	7.3	4.2
26-Dec	4.2	4.3	5.9	5.7	5.9	6.0	0.6	0.8	1.2	5.0	4.0	4.7	6.9	5.2
27-Dec	4.3	4.4	6.1	5.8	5.9	5.8	1.5	0.7	1.3	5.2	1.9	4.4	7.2	4.9
28-Dec	4.5	4.6	5.8	5.7	5.7	5.7	1.7	0.9	1.4	3.5	2.8	3.2	5.9	4.4
29-Dec	4.5	4.5	5.6	5.5	5.7	5.6	1.5	0.9	1.5	3.4	4.1	3.0	5.2	4.7
30-Dec	4.5	4.4	5.8	5.6	5.7	5.6	2.4	1	2.3	4.5	3.0	2.6	7.4	3.7
31-Dec	4.7	4.7	5.9	5.7	5.6	5.6	3.1	1.4	2.8	4.1	2.1	3.7	4.7	1.1
01-Jan	4.5	4.4	5.5	5.4	5.5	5.6	1.4	1.4	2.5	4.9	3.5	4.2	4.8	2.0
02-Jan	4.4	4.3	5.6	5.3	5.5	5.6	2.4	1.3	3	4.1	5.0	4.0	4.7	2.8
03-Jan	4.5	4.4	5.6	5.3	5.5	5.6	1.1	1	1.9	2.9	5.2	1.9	4.4	5.6
04-Jan	4.5	4.5	5.6	5.4	5.6	5.6	2.1	1.1	1.8	3.5	3.5	2.8	3.2	7.3
05-Jan	4.5	4.5	5.6	5.5	5.6	5.6	2.6	1	1.7	4.7	3.4	4.1	3.0	6.9
06-Jan	4.6	4.6	5.8	5.6	5.6	5.5	3.3	1.6	2.4	4.4	4.5	3.0	2.6	7.2
07-Jan	4.7	4.7	5.7	5.5	5.5	5.4	3.4	1.6	2.6	3.3	4.1	2.1	3.7	5.9
08-Jan	4.7	4.6	5.4	5.2	5.3	5.3	1.9	1.6	1.3	0.3	4.9	3.5	4.2	5.2
09-Jan	4.4	4.3	5.3	5	5.2	5.2	0.7	1.1	0.7	1.9	4.1	5.0	4.0	7.4

Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR-7	AIR-14	AIR-21	AIR-30
10-Jan	4.2	4.2	5.2	5	5.1	5.0	1.3	0.8	0.9	3.5	2.9	5.2	1.9	4.7
11-Jan	4.3	4.2	5.3	5	5	4.9	3.0	0.9	1.4	2.9	3.5	3.5	2.8	4.8
12-Jan	4.3	4.2	5.2	4.9	4.9	4.7	2.8	1.4		3.8	4.7	3.4	4.1	4.7
13-Jan	4.4	4.2	4.9	4.7	4.8	4.6	2.5	1.6	2.:	3.2	4.4	4.5	3.0	4.4
14-Jan	4.3	4.2	4.9	4.7	4.7	4.6	3.1	1.7	2.4	3.8	3.3	4.1	2.1	3.2
15-Jan	4.2	4.1	4.7	4.5	4.6	4.6	2.3	1.7	2.5	4.1	0.3	4.9	3.5	3.0
16-Jan	4.3	4.1	4.9	4.6	4.7	4.6	3.7	1.8	2.9	4.7	1.9	4.1	5.0	2.6
17-Jan	4.3	4.2	5.1	4.8	4.8	4.6	4.3	2	3.7	4.3	3.5	2.9	5.2	3.7
18-Jan	4.4		4.7	4.6	4.6	4.6	2.9	2	3	2.3	2.9	3.5	3.5	4.2
19-Jan	3.9	4::	4.5	4.3	4.4	4.6	0.9	1.5	1.8	2.7	3.8	4.7	3.4	4.0
20-Jan	3.6	3.5	4.5	4.2	4.4	4.4	0.0	0.9	0.4	2.2	3.2	4.4	4.5	1.9
21-Jan	3.7	3.6	4.5	4.2	4.3	4.2	0.1	0.6	0.1	1.9	3.8	3.3	4.1	2.8
22-Jan	3.7	3.6	4.3	4.2	4.2	4.2	0.4	0.4	0.1	2.5	4.1	0.3	4.9	4.1
23-Jan	3.7	3.6	4.6	4.3	4.3	4.2	2.5	0.7	1.1	5.9	4.7	1.9	4.1	3.0
24-Jan	4.1	3.9	4.8	4.5	4.5	4.2	4.7	1	3	7.7	4.3	3.5	2.9	2.1
25-Jan	4.3	4	4.8	4.5	4.4	4.2	5.2	1.7	3.8	7.7	2.3	2.9	3.5	3.5
26-Jan	4.1	3.9	4.6	4.3	4.3	4.1	4.3	2.3	3.3	5.0	2.7	3.8	4.7	5.0
27-Jan	4	3.8	4.5	4.2	4.3	4.2	3.4	2.2	3.4	5.7	2.2	3.2	4.4	5.2
28-Jan	4.4	4.1	4.9	4.6	4.6	4.2	6.2	2.2	4.2	7.4	1.9	3.8	3.3	3.5
29-Jan	4.6	4.2	4.7	4.5	4.4	3.9	5.9	2.7	4.6	7.9	2.5	4.1	0.3	3.4
30-Jan	4.5	4.2	4.6	4.3	4.2	3.7	5.5	3	4.7	7.6	5.9	4.7	1.9	4.5
31-Jan	4.3	3.9	4.5	4.2	4.1	3.5	6.2	2.9	4.8	9.8	7.7	4.3	3.5	4.1
01-Feb	4.3	3.9	4.2	4	3.8	3.4	6.1	2.9	4.4	9.8	7.7	2.3	2.9	4.9
02-Feb	4.4	3.9	4.3	4	3.8	3.4	6.1	3.4	4.7	7.7	5.0	2.7	3.8	4.1
03-Feb	4.2	3.7	3.9	3.7	3.6	3.3	4.1	3.1	4.1	3.7	5.7	2.2	3.2	2.9
04-Feb	3.7	3.4	3.7	3.4		3.3	2.4	2.5		3.5	7.4	1.9	3.8	3.5
05-Feb	3.3	3.1	3.7	3.4	5::	3.3	1.6	1.8	2.:	4.0	7.9	2.5	4.1	4.7
06-Feb	3.1	3	3.8	3.4	3.6	3.5	1.7	1.4	2.1	4.6	7.6	5.9	4.7	4.4
07- Feb	3.2	3.2		3.7	3.7	3.6	2.5	1.4	2.4	5.4	9.8	7.7	4.3	3.3
08-Feb	3.7	3.5	4.:	3.9	3.9	3.6	3.5	1.7	3.4	6.9	9.8	7.7	2.3	0.3
09-Feb	4	3.6	4.4	4.1	3.9	3.4	5.2	1.9	4.8	7.0		5.0	2.7	1.9
10-Feb	4.1	3.5	4.1	3.8	3.7	3.3	4.7	2.2	5.1	8.4	3::	5.7	2.2	3.5
11-Feb	4.1	3.6	4.3	3.8	3.8		5.5	2.8	5.2	9.3	3.5	7.4	1.9	2.9
12-Feb	4.2	3.7	4.2	3.8	3.7	3::	5.9	2.8	5.1	9.6	4.0	7.9	2.5	3.8
13-Feb	4.4	3.9	4.3	3.9	3.8	3.3	7.0	3.4	6	8.6	4.6	7.6	5.9	3.2
14-Feb	4.6	4	4.3	3.9	3.7	3.4	6.1	3.6	6.1	8.7	5.4	9.8	7.7	3.8
15-Feb	4.5	3.9	4.2	3.8	3.7	3.4	5.6	3.5	5.6	8.6	6.9	9.8	7.7	4.1
16-Feb	4.4	3.9	4.4	3.9	3.8	3.5	6.0	3.6	5.1	7.3	7:o	7.7	5.0	4.7
17-Feb	4.3	3.8	4.2	3.8	3.7	3.5	4.7	3.4	5.1	5.9	8.4	3.7	5.7	4.3
18-Feb	4.3	3.8	4.2	3.8	3.9	3.6	4.6	3.3	5.1	7.1	9.3	3.5	7.4	2.3
19-Feb	4.5	4.1	4.6	4.2	4.1	3.6	6.6	3.6	5.5	8.7	9.6	4.0	7.9	2.7
20-Feb	5	4.4	4.6	4.2	4.1	3.6	7.6	4.2	6.5	8.6	8.6	4.6	7.6	2.2
21-Feb	5.3	4.6	4.5	4.3	4	3.6	7.5	4.8	6.1	8.3	8.7	5.4	9.8	1.9
22-Feb	5.4	4.5	4.7	4.3	4.1	3.7	7.2	4.8	6.2	8.6	8.6	6.9	9.8	2.5
23- Feb	5.4	4.6	4.6	4.2	4.1	3.7	6.7	4.9	6.1	7.5	7.3	7.0	7.7	5.9
24- Feb	5.5	4.7	4.8	4.3	4.2	3.7	7.6	4.9	6.7	8.9	5.9	8.4	3.7	7.7
25-Feb	5.8	4.8	4.9	4.4	4.3	3.8	8.7	5.3	7.6	10.3	7.1	9.3	3.5	7.7
26- Feb	5.9	4.9	4.8	4.5	4.4	3.9	9.0	5.4	7.7	10.7	8.7	9.6	4:o	5:o

Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR-7	AIR-14	AIR-21	AIR-30
27-Feb	5.9	4.9	4.9	4.5	4.4	4.0	7.8	5.7	7.4	10.2	8.6	8.6	4.6	5.7
28-Feb	5.9	5.1	4.9	4.6	4.5	4.1	7.5	6	7.4	10.5	8.3	8.7	5.4	7.4
29-Feb	6	5.2		4.6	4.6	4.2	7.6	6.2	7.6	11.6	8.6	8.6	6.9	7.9
01-Mar	6.2	5.5	5.:	4.8	4.8	4.4	8.2	6.7	8	12.6	7.5	7.3	7.0	7.6
02-Mar	6.5	5.8	5.5	5.1	4.9	4.5	8.1	7.2	7.8	10.5	8.9	5.9	8.4	
03-Mar	6.5	5.8	5.5	5.1	5	4.6	8.0	7.4	7.7	11.1	10.3	7.1	9.3	8:X
04-Mar	6.8	6.1	5.9	5.4	5.2	4.7	8.7	7.5	7.9	11.0	10.7	8.7	9.6	
05-Mar	6.7	6.1	5.6	5.3	5.1	4.8	7.4	7.6	7	9.6	10.2	8.6	8.6	3::
06-Mar	6.7	6.2	5.8	5.4	5.2	4.9	7.5	7.9	7.3	11.0	10.5	8.3	8.7	3.5
07-Mar	7	6.4	6	5.5	5.6	5.1	8.4	8.1	7.9	11.4	11.6	8.6	8.6	4.0
08-Mar	7.4	6.9	6.3	5.9	5.7	5.3	9.3	8.5	8.2	12.0	12.6	7.5	7.3	4.6
09-Mar	7.5	7	6.4	6	5.9	5.6	8.7	8.9	7.9	12.1	10.5	8.9	5.9	5.4
10-Mar	7.5	7.1	6.7	6.3	6.3	6.0	7.9	8.8	7.6	10.8	11.1	10.3	7.1	6.9
11-Mar	7.6	7.2	7.1	6.6	6.6	6.3	7.8	8.6	7.8	11.7	11.0	10.7	8.7	7.0
12-Mar	7.8	7.5	7.3	6.9	6.8	6.5	8.2	8.6	8.1	11.6	9.6	10.2	8.6	8.4
13-Mar	8.1	7.7	7.5	7.1	6.9	6.6	8.9	8.6	8.7	13.5	11.0	10.5	8.3	9.3
14-Mar	8.4	7.9	7.8	7.2	7.1	6.8	9.4	8.8	9.2	13.2	11.4	11.6	8.6	9.6
15-Mar	8.8	8.2	8.2	7.5	7.4	6.9	10.1	9	10	15.9	12.0	12.6	7.5	8.6
16-Mar	9	8.4	8	7.7	7.5	7.0	9.3	9.1	10	11.7	12.1	10.5	8.9	8.7
17-Mar	8.6	8.1	7.8	7.5	7.4	7.1	8.2	9.1	9.3	9.3	10.8	11.1	10.3	8.6
18-Mar	8.4	8	8.1	7.5	7.4	6.9	8.4	8.7	8.8	10.4	11.7	11.0	10.7	7.3
19-Mar	8.3	7.8	7.7	7.4	7.2	6.9	8.0	8.6	8.4	10.9	11.6	9.6	10.2	5.9
20-Mar	8.4	8	8.1		7.5	7.1	8.1	8.9	8.5	12.4	13.5	11.0	10.5	7.1
21-Mar	8.6	8.3	8.3	3::	7.6	7.3	8.2	9	8.5	12.2	13.2	11.4	11.6	8.7
22-Mar	8.8	8.5	8.5	7.9	7.9	7.7	8.2	9.1	8.7	12.5	15.9	12.0	12.6	8.6
23-Mar	9	8.6	8.8	8.2	8.3	8.0	8.5	9.2	9.1	12.4	11.7	12.1	10.5	8.3
24-Mar	9.2	8.8	8.9	8.5	8.5	8.2	8.9	9.2	9.2	12.7	9.3	10.8	11.1	8.6
25-Mar	9.4	9.1	9.4	8.8	8.7	8.3	9.3	9.3	9.6	12.3	10.4	11.7	11.0	7.5
26-Mar	9.7	9.3	9.4	8.9	8.7	8.3	9.1	9.6	10	11.7	10.9	11.6	9.6	8.9
27-Mar	9.6	9.3	9.2	8.9	8.8	8.3	9.1	9.5	9.7	11.7	12.4	13.5	11.0	10.3
28-Mar	9.3	9.1	9.2	8.8	8.7	8.2	8.0	9.4		11.5	12.2	13.2	11.4	10.7
29-Mar	9.2	9	9	8.7	8.6	8.4	8.0	9.1	8.3	11.3	12.5	15.9	12.0	10.2
30-Mar	9.4	9.2	9.2	9	8.9	8.6	9.4	9.6	9.5	14.0	12.4	11.7	12.1	10.5
31-Mar	10.2	9.8	9.8	9.5	9.3	8.8	10.7	10.3	11.2	17.2	12.7	9.3	10.8	11.6
01-Apr	10.8	10.3	10.1	9.7	9.5	8.9	11.5	11.1	11.9	17.4	12.3	10.4	11.7	12.6
02-Apr	11.2	10.7	10.3	9.9	9.7	9.3	12.0	11.5	12.7	17.8	11.7	10.9	11.6	10.5
03-Apr	11.5	10.9	10.5	10.2	10.1	9.5	12.0	11.9	12.9	17.9	11.7	12.4	13.5	11.1
04-Apr	11.5	11.1	10.6	10.3	10	9.4	11.1	12	11.9	12.0	11.5	12.2	13.2	11.0
OS-Apr	11	10.7	10.1	9.8	9.7	9.4	9.0	11.3	10.3	8.9	11.3	12.5	15.9	9.6
06-Apr	10.5	10.3	9.8	9.6	9.5	9.6	7.5	10.9	9.2	8.4	14.0	12.4	11.7	11.0
07-Apr	9.8	9.6	9.5	9.5	9.6	9.7	6.2	9.7	8	8.5	17.2	12.7	9.3	11.4
08-Apr	9.5	9.3	9.8	9.7	9.9	9.8	7.3	9	7.9	10.2	17.4	12.3	10.4	12.0
09-Apr	9.5	9.3	10.2	10	10	9.8	8.7	8.4	8.5	11.3	17.8	11.7	10.9	12.1
10-Apr	9.7	9.4	10.4	10.2	10.2	9.8	9.4	8.3	9.6	11.4	17.9	11.7	12.4	10.8
11-Apr	9.6	9.3	10.5	10.3	10.2	9.8	9.4	8.2	9.3	12.2	12.0	11.5	12.2	11.7
12-Apr	9.8	9.6	10.7	10.5	10.3	10.0	10.4	8.8	9.8	14.0	8.9	11.3	12.5	11.6

Date	RK 265	RK 287	RK 303	RK 312	RK 347	RK 398	IMNAHA	SALMON	G_RONDE	AIR	AIR-7	AIR-14	AIR-21	AIR-30
13-Apr	10.4	10.2	10.9	10.7	10.7	10.1	11.1	9.8	10.6	15.9	8.4	14.0	12.4	13.5
14-Apr	11.1	10.8	11.4	11.1	10.8	10.0	11.3	10.5	11.4	16.0	8.5	17.2	12.7	13.2
15-Apr	11.7	11.2	11.4	11	10.8	10.1	11.5	11	11.9	15.8	10.2	17.4	12.3	15.9
16-Apr	11.8	11.4	11.5	11.1	10.9	10.3	12.1	11.3	12.4	16.5	11.3	17.8	11.7	11.7
17-Apr	11.8	11.5	11.4	11.1	11	10.5	11.5	11.4	12	13.6	11.4	17.9	11.7	9.3
18-Apr	11.4	11.2	11.3	11.1	10.8	10.4	9.8	11	10.4	11.8	12.2	12.0	11.5	10.4
19-Apr	11	10.8	11.2	11	10.8	10.5	9.6	10.6	10.5	13.4	14.0	8.9	11.3	10.9
20-Apr	11.3	10.9	11.6	11.3	11.2	10.7	11.1	10.6	11.3	17.0	15.9	8.4	14.0	12.4
21-Apr	11.3	11	11.6	11.4	11.2	10.7	11.0	10.6	11	12.7	16.0	8.5	17.2	12.2
22-Apr	10.8	10.6	11.2	11	11	10.7	9.5	10.3	10.1	11.3	15.8	10.2	17.4	12.5
23-Apr	10.8	10.6	11.1	11	11	11.0	9.0	10.4	10.1	11.7	16.5	11.3	17.8	12.4
24-Apr	11	10.7	11.6	11.5	11.5	11.1	9.6	10.2	10.5	14.6	13.6	11.4	17.9	12.7
25-Apr	11.5	11.1	12.2	11.9	11.8	11.2	11.5	10.5	11.9	17.4	11.8	12.2	12.0	12.3
26-Apr	12.1	11.6	12.5	12.2	11.8	11.0	12.7	10.7	13.2	19.4	13.4	14.0	8.9	11.7
27-Apr	12.4	11.8	12.3	12	11.7	11.1	13.1	11.3	14.2	19.1	17.0	15.9	8.4	11.7
28-Apr	12.8	12.3	12.4	12.1	11.8	11.2	14.1	12.1	14.7	19.5	12.7	16.0	8.5	11.5
29-Apr	13.3	12.8	12.8	12.4	12	11.2	14.2	12.9	14.8	21.4	11.3	15.8	10.2	11.3
30-Apr	13.3	12.8	12.7	12.4	11.9	11.3	13.3	12.9	13.9	16.1	11.7	16.5	11.3	14.0
01-May	12.5	12.1	12.1	11.8	11.7	11.5	11.1	11.9	12.3	14.8	14.6	13.6	11.4	17.2
02-May	12.2	11.9	12.3	12.1	12.1	11.9	11.6	11.6	12.4	18.1	17.4	11.8	12.2	17.4
03-May	12.6	12.2	12.9	12.7	12.6	12.1	13.0	11.6	13.9	21.1	19.4	13.4	14.0	17.8
04-May	12.9	12.3	13.1	12.8	12.6	12.1	13.7	11.8	14.9	21.2	19.1	17.0	15.9	17.9
05-May	13.1	12.6	13.2	12.9	12.8	12.4	14.3	12.3	15.6	22.1	19.5	12.7	16.0	12.0
06-May	13.6	13.1	13.6	13.3	13.2	12.6	14.9	12.8	16.2	23.5	21.4	11.3	15.8	8.9
07-May	14	13.4	14.3	13.9	13.5	12.7	15.0	13	16.5	22.6	16.1	11.7	16.5	8.4
08-May	13.8	13.2	14.1	13.8	13.4	12.8	13.6	12.8	15.4	19.9	14.8	14.6	13.6	8.5
09-May	12.9	12.5	13.5	13.4	13	12.8	11.4	12.1	13	14.6	18.1	17.4	11.8	10.2
10-May	12.6	12.2	13.4	13.3	13.3	13.1	11.9	11.8	13.1	18.3	21.1	19.4	13.4	11.3
11-May	12.4	11.9	13.6	13.5	13.5	13.2	12.0	11.3	12.8	16.0	21.2	19.1	17.0	11.4
12-May	12.2	11.9	13.7	13.6	13.3	13.3	11.3	11.2	12.7	15.3	22.1	19.5	12.7	12.2

Appendix 5. Summary of the number of subyearling chinook salmon marked with coded wire tags and brands or considered not suitable for marking at McNary Dam during June to August, 1991.

Date	cvr Cods	Brand	MARKED Marked & Bypassed	held & Trans.	Total Mark.	48 HOUR DELAYED MORTALITY AND TAG LOSS #Morts	%Mort	#Lost Tags	%Tag Loss	UNMARKABLE Prev. Branded	Desc.	Under- Size	Other Unmark.	Total Unmark.
Jun 20	27/11	LAR1	1,302	125	1.427	0	0.0	0	0.0	4	122	54	640	820
Jun 21	27/11	LAR4	985	100	1,085	0	0.0	0	0.0	4	86	103	453	646
Jun 22	27/11	LAB3	1,137	100	1.237	0		0	-.-	6	121	107	512	746
Jun 23	27/11	LA62	1.843	100	1.943	2	2.0 00	0	0.0	10	152	89	683	934
Jun 24	27/11	RAR1	1.954	125[a]	2,079	0	0.0	0	0.0	10	185	67	605	867
Jun 25	27/11	RAR2	3,997	100	4,097	0	0.0	0	0.0	16	238	140	753	1,147
Jun 26	27/10	RAR3	5,486	100	5,586	0	0.0	1	1.0	33	368	107	843	1,351
Jun 27	27/10	RAR4	6.514	100	6.614	0	0.0	0	0.0	46	446	63	709	1.244
Jun 28	27/9	RA2K3	4.992	100	5,092	0	0.0	0	0.0	61	286	91	478	888
Jun 29	27/9	LA2P1	4,772	100	4,872	2	2.0	0	0.0	61	289		456	897
Jun 30	27/9	RA2P1	1,859	100	1,959	0	0.0	0	0.0	37	95	30	152	314
Subtotal			34,841	1,150	35.991	4	0.4	1	0.1	288	2,388	894	6.284	9,854
Jul 09	27/8	RA2V1	2,484	100	2.584	0	0.0	0	0.0	95	121	6	206	428
Jul 10	27/8	RA2V3	3.358	100	3,458	0	0.0	0	0.0					649
Jul 11	27/8	LA2V1	5,860	100	5.960	0	0.0	0	0.0	199	365	25	392	1,153
Jul 12	27/7	LA2V3	7,015	100	7.115	0	0.0	0	0.0	175	378	3	474	1,030
Jul 13	27/7	LA2S1	4,789	100	4.889	1	1.0	1	1.0	83	207	14	409	713
Jul 14	27/6	LA2S3	1,718	100	1.818	0	0.0	0	0.0	32	107	1	273	413
Jul 15	27/6	RA2S1	4,633	100	4,733	0	0.0	0	0.0	70	265	15	303	653
Jul 16	27/6	RA2S3	5.349	100	5,449	1	1.0	0	0.0	84	249	5	398	736
Subtotal			35,206	800	36,006	2	0.3	1	0.1	851	1,908	87	2,929	5,775
Jul 24	27/5	RA2K1	2,904	100	3,004	1	1.0	0	0.0	7	208	4	177	396
Jul 25	27/5	LA2K1	2,626	100	2,726	2	2.0	0	0.0	9	144	1	171	325
Jul 26	27/5	LA263	938	100	1,038	1	1.0	0	0.0	4	85	1	110	200
Jul 27	27/5	RA9T1	2,495	100	2,595	12	12.0	0	0.0					640
Jul 28	27/5	RA9T3	1.279	100	1.379	1	1.0	0	0.0	33	101	3	134	262
Jul 29	27/5	LA9T1	1.247	50	1.297	0	0.0	0	0.0	2	86	1	74	163
Jul 30	26/63	LA9T3	7.461	100	7,561	1	1.0	0	0.0	30	492	1	351	874
Jul 31	26/63	LA2P3	4,363	100	4,463	2	2.0	0	0.0	18	284	1	252	555
AUG 1	26/62	RA2P3	3,934	100	4,034	0	0.0	0	0.0	11	247	0	154	412
AUG 2	26/62	RARH1	4.121	100	4,221	1	1.0	0	0.0	20	211	0	274	505
AUG 3	26/62	LARH1	3,673	100	3,773	1	1.0	0	0.0	16	234	0	354	604
Subtotal			35,041	1,050	36,091	22	2.1	0	0.0	159	2,353	14	2,410	4.936

SUMMARY	MARKED Barked & Bypassed	Held & Trans.	Total Mark.	48 HOUR DELAYED MORTALITY AND TAG LOSS #Morts	%Mort	#Lost Tags	%Tag Loss	UNMARKABLE Prev. Branded	Desc	Under- Size	Other Unmark.	Total Unmark.
TOTAL	105,088	3,000	108,088	28	0.9	2	0.1	1,298	6,649	995	11.623	20.565

[a] The total includes 100 fish held for delayed mortality on June 24. 1991.

APPENDIX 6. Data used for fall chinook salmon size versus emigration
rate regression analysis.

TAG_FILE$	TAG_IDS	REL SZ	LN_SZ	REL KM	REL_DAT	OBS_DATE	TRV TIME	MIGR RATE
WPC91149.R17	7F7D1E6C79	68.0	4.2195	217	05/29/91	07/24/91	56.2	0.8
WPC91150.G29	7F7D1E6855	64.0	4.1589	229	05/30/91	07/15/91	46.0	1.2
WPC91150.G29	7F7D17715F	62.0	4.1271	229	05/30/91	07/25/91	55.9	1
WPC91150.R16	7F7D1E4C28	58.0	4.0604	216	05/30/91	08/06/91	68.3	0.6
WPC91150.G29	7F7D1E7C77	55.0	4.0073	229	05/30/91	08/02/91	64.1	0.9
WPC91155.G35	7F7D1E3C3E	68.0	4.21%	235	06/04/91	07/18/91	44.9	1.4
WPC91157.G42	7F7D1E4569	56.0	4.0254	242	06/06/91	08/10/91	66.2	1
WPC91162.G42	7F7D1E4651	67.0	4.2047	242	06/11/91	07/21/91	40.4	1.7
WPC91162.G50	7F7D1E3A6F	78.0	4.3567	250	06/11/91	07/21/91	40.0	1.9
WPC91162.G42	7F7D1E3B2B	64.0	4.1589	242	06/11/91	07/25/91	43.8	1.6
WPC91163.G35	7F7D1E3D4B	78.0	4.3567	235	06/12/91	07/22/91	39.7	1.6
WPC91163.G35	7F7D1E3B35	78.0	4.3567	235	06/12/91	09/05/91	84.4	0.7
WPC91164.G29	7F7D1E4D71	64.0	4.1589	229	06/13/91	07/25/91	42.2	1.3
WPC91164.G26	7F7D181304	66.0	4.1897	226	06/13/91	07/20/91	37.0	1.4
WPC91164.G26	7F7D1D5913	60.0	4.0943	226	06/13/91	08/22/91	70.4	0.8
WPC91164.G26	7F7D1E5172	74.0	4.3041	226	06/13/91	07/30/91	46.6	1.1
WPC91164.G26	7F7D1E5101	70.0	4.2485	226	06/13/91	07/23/91	39.9	1.3
WPC91164.G29	7F7D1E4750	98.0	4.585	229	06/13/91	07/18/91	35.6	1.6
WPC91169.G42	7F7D1D5621	97.0	4.5747	242	06/18/91	07/18/91	30.6	2.3
WPC91169.G32	7F7D07537C	99.0	4.5951	232	06/18/91	07/08/91	19.7	3
WPC91169.G42	7F7D075374	98.0	4.585	242	06/18/91	07/09/91	21.1	3.3
WPC91169.G26	7F7D1D5960	94.0	4.5433	226	06/18/91	06/30/91	12.2	4.3
WPC91169.G42	7F7D1D5821	70.0	4.2485	242	06/18/91	07/25/91	36.5	1.9
WPC91169.G42	7F7D075937	84.0	4.4308	242	06/18/91	08/01/91	44.2	1.6
WPC91170.G42	7F7D042954	91.0	4.5109	242	06/19/91	07/07/91	18.1	3.8
WPC91170.G26	7F7D074E51	81.0	4.3945	226	06/19/91	07/25/91	35.4	1.5
WPC91175.G42	7F7D1E3F08	84.0	4.4308	242	06/24/91	07/17/91	22.8	3
WPC91175.G42	7F7D07513C	82.0	4.4067	242	06/24/91	07/13/91	18.5	3.7
WPC91175.G26	7F7D075869	74.0	4.3041	226	06/24/91	07/31/91	36.7	1.4
WPC91175.G42	7F7D07502A	95.0	4.5539	242	06/24/91	07/22/91	27.7	2.5
WPC91176.G42	7F7D152E70	91.0	4.5109	242	06/25/91	08/11/91	47.0	1.5
WPC91176.G42	7F7D165111	102.0	4.625	242	06/25/91	07/11/91	16.4	4.2
WPC91176.G42	7F7D165972	97.0	4.5747	242	06/25/91	07/20/91	25.2	2.7
WPC91176.G42	7F7D165E31	90.0	4.4998	242	06/25/91	07/25/91	29.5	2.3
WPC91176.G42	7F7D152B08	78.0	4.3567	242	06/25/91	08/28/91	63.4	1.1
WPC91176.G42	7F7D153F6D	98.0	4.585	242	06/25/91	07/15/91	19.8	3.5
WPC91176.G42	7F7D153B00	108.0	4.6821	242	06/25/91	07/09/91	13.5	5.1
WPC91176.G42	7F7D152A19	75.0	4.3175	242	06/25/91	07/27/91	31.9	2.2
WPC91176.G42	7F7D154221	94.0	4.5433	242	06/25/91	07/24/91	28.8	2.4
WPC91176.G42	7F7D074C21	106.0	4.6634	242	06/25/91	07/20/91	24.4	2.8
WPC91176.G42	7F7D152B0A	80.0	4.382	242	06/25/91	07/23/91	27.9	2.5
WPC91176.G42	7F7D152E2E	104.0	4.6444	242	06/25/91	07/25/91	30.0	2.3
WPC91176.G42	7F7D153F7A	88.0	4.4773	242	06/25/91	07/24/91	29.1	2.4
WPC91176.G42	7F7D152A3C	98.0	4.585	242	06/25/91	07/25/91	29.8	2.3
WPC91176.G42	7F7D15311A	97.0	4.5747	242	06/25/91	07/24/91	28.5	2.4
WPC91176.G42	7F7D165976	72.0	4.2767	242	06/25/91	07/25/91	30.0	2.3
WPC91176.G42	7F7D16402F	88.0	4.4773	242	06/25/91	07/15/91	19.7	3.5
WPC91176.G42	7F7D165D76	87.0	4.4659	242	06/25/91	07/24/91	29.0	2.4
WPC91176.G42	7F7D07575E	83.0	4.4188	242	06/25/91	08/03/91	39.5	1.7
WPC91176.G42	7F7D075949	97.0	4.5747	242	06/25/91	07/13/91	18.0	3.8
WPC91182.G26	7F7D1E3C45	89.0	4.4886	226	07/01/91	07/19/91	17.4	3
WPC91182.G26	7F7D1E3C57	96.0	4.5644	226	07/01/91	07/24/91	23.0	2.3
WPC91182.G26	7F7E342416	106.0	4.6634	226	07/01/91	07/20/91	19.0	2.8
WPC91183.G42	7F7D154618	91.0	4.5109	242	07/02/91	08/02/91	31.3	2.2
WPC91183.G42	7F7D1E4207	102.0	4.625	242	07/02/91	07/20/91	17.8	3.9
WPC91184.G42	7F7D074606	94.0	4.5433	242	07/03/91	07/28/91	25.0	2.8
WPC91184.G26	7F7D1E3930	97.0	4.5747	226	07/03/91	08/03/91	31.1	1.7
WPC91184.G42	7F7D15310C	79.0	4.3694	242	07/03/91	08/03/91	31.1	2.2
WPC91164.G26	7F7D1E3D71	94.0	4.5433	226	06/13/91	06/28/91	14.6	3.6

EXCLUDED OUTLIERS: 7F7D11492E, 7F7D074E6F, 7F7E355201,7F7D074F1D, 7F7D1D6B46, 7F7D075173

Appendix 7. Data used for fall chinook salmon emigration rate regression analysis.

TAG-FILES	TAG-IDS	REL_SZ	LN_SZ	MGR_FLOW	LN_FLOW	MGR_TEMP	LN_TEMP	REL_TEMP	LN_REL_T	MIGR_RATE
WPC91170.G42	7F7D042954	91.0	4.5109	61.1	4.1127	16.2	2.7845	13.5	2.6027	3.8
WPC91184.G42	7F7D074606	94.0	4.5433	33.4	3.5074	20.4	3.0152	15	2.7081	2.8
WPC91176.G42	7F7D074C21	106.0	4.6634	48.1	3.8720	18.3	2.9069	15	2.7081	2.8
WPC91170.G26	7F7D074E51	81.0	4.3944	44.6	3.7968	18.7	2.9266	13.5	2.6027	1.6
WPC91175.G42	7F7D07502A	95.0	4.5539	45.9	3.8268	18.5	2.91%	15	2.7081	2.5
WPC91175.G42	7F7D07513C	82.0	4.4067	53.6	3.9807	17.8	2.8795	15	2.7081	4.1
WPC91169.G42	7F7D075374	98.0	4.585	59.4	4.0835	16.4	2.7960	14	2.6391	3.3
WPC91169.G32	7F7D07537C	99.0	4.5951	60.3	4.0997	16.2	2.7877	13.5	2.6027	3
WPC91176.G42	7F7D07575E	83.0	4.4188	36.5	3.5979	19.8	2.9874	14	2.6391	1.8
WPC91175.G26	7F7D075869	74.0	4.3041	31.8	3.4589	20.6	3.0244	15	2.7081	1.9
WPC91169.G42	7F7D075937	84.0	4.4308	42.0	3.7376	19.0	2.9418	14	2.6391	1.6
WPC91176.G42	7F7D075949	97.0	4.5747	54.2	3.9922	17.7	2.8708	15	2.7081	3.8
WPC91176.G42	7F7D152A19	75.0	4.3175	35.2	3.5604	20.2	3.0068	15	2.7081	2.7
WPC91176.G42	7F7D152A3C	98.0	4.585	42.8	3.7554	19.0	2.9444	15	2.7081	2.3
WPC91176.G42	7F7D152B08	78.0	4.3567	26.4	3.2715	21.1	3.0478	15	2.7081	1.2
WPC91176.G42	7F7D152B0A	80.0	4.382	42.8	3.7564	19.1	2.9498	15	2.7081	2.8
WPC91176.G42	7F7D152E2E	104.0	4.6444	42.8	3.7554	19.0	2.9444	15	2.7081	2.3
WPC91176.G42	7F7D152E70	91.0	4.5109	33.6	3.5134	20.1	3.0016	15	2.7081	1.5
WPC91184.G42	7F7D15310C	79.0	4.3694	27.5	3.3132	21.0	3.0452	15	2.7081	2.6
WPC91176.G42	7F7D15311A	97.0	4.5747	43.5	3.7736	18.9	2.9387	15	2.7081	2.4
WPC91176.G42	7F7D153B00	108.0	4.6821	56.6	4.0359	17.1	2.8398	15	2.7081	5.1
WPC91176.G42	7F7D153F6D	98.0	4.585	52.4	3.9593	17.9	2.8835	15	2.7081	3.5
WPC91176.G42	7F7D153F7A	88.0	4.4773	43.5	3.7736	18.9	2.9387	15	2.7081	2.4
WPC91176.G42	7F7D154221	94.0	4.5433	43.5	3.7736	18.9	2.9387	15	2.7081	2.4
WPC91183.G42	7F7D154618	91.0	4.5109	31.9	3.4633	20.6	3.0248	15	2.7081	2.2
WPC91176.G42	7F7D16402F	88.0	4.4773	52.4	3.9593	17.9	2.8835	15	2.7081	3.5
WPC91176.G42	7F7D165111	102.0	4.625	55.3	4.0133	17.4	2.8540	15	2.7081	4.2
WPC91176.G42	7F7D165972	97.0	4.5747	47.0	3.8506	18.4	2.9131	15	2.7081	2.7
WPC91176.G42	7F7D165976	72.0	4.2767	33.3	3.5041	20.3	3.0113	15	2.7081	3.4
WPC91176.G42	7F7D165D76	87.0	4.4659	43.5	3.7736	18.9	2.9387	15	2.7081	2.4
WPC91176.G42	7F7D165E31	90.0	4.4998	42.8	3.7554	19.0	2.9444	15	2.7081	2.3
WPC91150.G29	7F7D17715F	62.0	4.1271	47.9	3.8695	18.0	2.8906	11	2.3979	1.4
WPC91164.G26	7F7D181304	66.0	4.1897	45.5	3.8178	18.7	2.9293	13.5	2.6027	2.3
WPC91169.G42	7F7D1D5621	97.0	4.5747	51.9	3.9487	17.5	2.8642	14	2.6391	2.3
WPC91169.G42	7F7D1D5821	70.0	4.2485	40.5	3.7015	19.4	2.9673	14	2.6391	2.6
WPC91164.G26	7F7D1D5913	60.0	4.0943	25.8	3.2521	21.2	3.0553	13	2.5649	
WPC91169.G26	7F7D1D5960	94.0	4.5433	63.7	4.1548	15.0	2.7109	13.5	2.6027	4.:
WPC91184.G26	7F7D1E3930	97.0	4.5747	30.4	3.4154	20.7	3.0312	18	2.8904	1.7
WPC91162.G50	7F7D1E3A6F	78.0	4.3567	50.9	3.9292	17.5	2.8645	14	2.6391	2.2
WPC91162.G42	7F7D1E3B2B	64.0	4.1589	41.2	3.7185	19.3	2.9595	13	2.5649	2.4

WPC91163.G35	7F7D1E3B35	78.0	4.3567	31.4	3.4474	20.1	2.9987	12	2.4849	0.8
WPC91155.G35	7F7D1E3C3E	68.0	4.2195	52.7	3.9651	17.3	2.8515	12	2.4869	1.9
WPC91182.G26	7F7D1E3C45	89.0	4.4886	44.1	3.7854	19.2	2.9548	16	2.7726	3
WPC91182.G26	7F7D1E3C57	96.0	4.5643	38.3	3.6458	19.8	2.9863	16	2.7726	2.3
WPC91163.G35	7F7D1E3D4B	78.0	4.3567	49.6	3.9049	17.8	2.8781	12	2.4849	1.8
WPC91164.G26	7F7D1E3D71	94.0	4.5433	67.5	4.2115	14.5	2.6723	13	2.5649	3.6
WPC91175.G42	7F7D1E3F08	84.0	4.4308	50.3	3.9179	18.1	2.8961	12	2.4849	3.1
WPC91183.G42	7F7D1E4207	102.0	4.625	40.6	3.7028	19.5	2.9730	16	2.7726	3.9
WPC91157.G42	7F7D1E4569	56.0	4.0254	28.8	3.3592	20.8	3.0362	12	2.4849	1.7
WPC91162.G42	7F7D1E4651	67.0	4.2047	47.7	3.8639	18.2	2.9012	13	2.5649	2.4
WPC91164.G29	7F7D1E4750	98.0	4.585	54.9	4.0057	17.0	2.8319	13	2.5649	1.6
WPC91150.R16	7F7D1E4C28	58.0	4.0604	38.2	3.6418	19.5	2.9700	9	2.1972	0.9
WPC91164.G29	7F7D1E4D71	64.0	4.1589	40.5	3.7015	19.4	2.9673	12.5	2.5257	2
WPC91164.G26	7F7D1E5101	70.0	4.2485	45.6	3.8190	18.5	2.9199	13	2.5649	1.7
WPC91164.G26	7F7D1E5172	74.0	4.3041	41.3	3.7209	19.1	2.9505	13.5	2.6027	1.4
WPC91150.G29	7F7D1E6B55	64.0	4.1589	57.4	4.0508	16.7	2.8126	11	2.3979	1.8
WPC91149.R17	7F7D1E6C79	68.0	4.2195	52.3	3.9573	17.5	2.8617	11	2.3979	1
WPC91150.G29	7F7D1E7C77	55.0	4.0073	40.2	3.6946	19.2	2.9569	11	2.3979	1.3
WPC91182.G26	7F7E342416	106.0	4.6634	41.8	3.7328	19.4	2.9642	16	2.7726	2.8